AN EXPLORATORY STUDY ON FEATURES OF INTELLIGENT OFFICE BUILDINGS AND DEVELOPMENT OF AN ASSESSMENT TOOL

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ABSTRACT

AN EXPLORATORY STUDY ON FEATURES OF INTELLIGENT OFFICE BUILDINGS AND DEVELOPMENT OF AN ASSESSMENT TOOL

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Intelligent office buildings have a high-tech image that embraces advanced technologies to enhance the quality of life for building occupants and energy efficiency. The literature's exploration of the Intelligent Building (IB) concept indicated that the concept has broad aspects, which resulted in losing its focus. In this regard, this thesis aims to address two central questions of how the IB concept is currently interpreted by the building sector representatives and what are the intelligent features of an IB. A survey was created within the context of earlier IB definitions, intelligence assessment methods, and a preliminary study conducted for figuring out the impact of passive design approach and utilization of active system on building energy performance. The survey was designed to collect the experts' perspectives and determine the importance levels of the IB features which were validated by a focus group before its distribution. Based on the analysis of survey findings, four conflicting issues regarding the IB concept are identified. Representing the recent situation, a new approach to the intelligent office building concept is described in terms of its behavior and basic design principle. Finally, a feature-based intelligence assessment tool for an office building was developed and validated to help the decision-makers during the pre-design stage. The thesis concludes with the recommendations for the successful application of the IB concept and future investigations.

Keywords: Intelligent Buildings, Building Intelligence Assessment, Smart Buildings, Intelligent Building Design

ÖZ

AKILLI OFİS BİNALARININ ÖZELLİKLERİNİN BELİRLENMESİ VE ÖLÇÜLMESİ İÇİN ARAÇ GELİŞTİRİLMESİ

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Akıllı ofis binaları, bina sakinlerinin yaşam kalitesini ve enerji verimliliğini artırmak için ileri teknolojileri kullanmasından dolayı yüksek teknolojik bir imaja sahiptir. Akıllı bina kavramı üzerine yapılan literatür araştırması sonucunda kavrama ait odağın çok farklı yönleri olduğu ve bu sebeple temel anlamını kaybettiği anlaşılmıştır. Bu bağlamda, bu tez, akıllı bina kavramının şu anda bina sektörü temsilcileri tarafından nasıl yorumlandığını ve akıllı özelliklerinin neler olduğuna ilişkin iki adet temel soruyu ele almayı amaçlamaktadır. Daha önceki akıllı bina tanımları, değerlendirme yöntemleri ve pasif tasarım yaklaşımının ve aktif sistem kullanımının bina enerji performansı üzerindeki etkisini ortaya çıkarmak için yapılan bir ön çalışma sonuçlarına bağlı olarak bir anket oluşturulmuştur. Anket, uzmanların bakış açılarını toplamak ve dağıtılmadan önce bir odak grup tarafından doğrulanan akıllı bina özelliklerinin önem düzeylerini öğrenmek için tasarlanmıştır. Anket bulgularının analizine bağlı olarak, akıllı bina kavramına ilişkin dört çelişkili konu tartışılmıştır. Buna göre, davranış ve temel tasarım ilkesi açısından akıllı ofis bina konseptine yeni bir yaklaşım sunulmuştur. Son olarak, ofis binalarının akıllı bina özelliklerinin değerlendirilmesi amacı ile bir araç geliştirilmiş ve uzmanlar tarafından doğrulanmıştır. Tez, akıllı binaların başarılı bir şekilde uygulanması ve gelecekteki araştırmalar için önerilerle sona ermektedir.

Anahtar Kelimeler: Akıllı Binalar, Akıllı Bina Performans Değerlendirmesi, Akıllı Bina Tasarımı

Dedicated to my beloved family

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LIST OF ABBREVIATIONS

ABBREVIATIONS

ADV	Advanced Technology
AI	Artificial Intelligence
AIIB	Asian Institute of Intelligent Buildings
AmI	Ambient Intelligence
ANN	Artificial Neural Networks
ANOVA	One-way Analysis of Variance
ASHRAE	American Society of Heating Refrigeration and Air-conditioning Engineers
BACnet	Building Automation and Control Network
BAS	Building Automation System
BCS	Building Control System
BM	Building Management
BMS	Building Management System
BREEAM	Building Research Establishment Environmental Assessment Method
BRM	Building Rating Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CI	Computational Intelligence
CPS	Cyber Physical System
CoP	Coefficient of Performance
DALI	Digital Addressable Lighting Control
DNN	Deep Neural Networks
DM	Design Management
DSF	Double Skin Facade
EPS	Expanded Polystyrene Foam
GBTool	Green Building Assessment Tool
GBC	Green Building Challenge
GPS	Global Positioning System
HVAC	Heating, Ventilating and Air Conditioning
IATOB	Intelligence Assessment Tool for Office Buildings
IB	Intelligent Building

IBI	Intelligent Building Index
IBMS	Integrated Building Management System
ICT	Information and Communication Technologies
IOB	Intelligent Office Building
IoT	Internet of Things
IoIT	Internet of Intelligent Things
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
KPIs	Key Performance Indicators
LEED	Leadership in Energy and Environmental Design
LCC	Life Cycle Costing
MEMS	Micro-Electro-Mechanical Systems
ML	Machine Learning
MPC	Model Predictive Control
MRT	Mean radiant temperature
MSIR	Magnitude of Systems' Integration
NEST	Next Evolution in Sustainable Building Technologies
NN	Neural Network
NPV	Net Present Value
PCM	Phase Changing Material
PEF	Primary Energy Factor
PoE	Post Occupancy Evaluation Method
RFID	Radio-Frequency IDentification
SBTool	Sustainable Building Assessment Tool
SGHC	Solar Gain Heat Coefficient
SPSS	Statistical Package for Social Sciences
TRNSYS	Transient System Simulation Tool
TS	Turkish Standards
U-VALUE	Overall Heat Transfer Coefficient
WSN	Wireless Sensor Networks
WWR	Windows to Wall Ratio
XPS	Extruded Polystyrene
ZEB	Zero Energy Building
ZNEB	Zero Net Energy Building

LIST OF SYMBOLS

SYMBOLS

Definition	**Symbol**	**Unit**
Overall Heat Transfer Coefficient	U	W/m^2K
Yearly Heating Energy Need	$Q_{heating}$	kWh/m^2, year
Yearly Cooling Energy Need	$Q_{cooling}$	kWh/m^2, year
Yearly Electricity Energy Need	$Q_{electricity}$	kWh/m^2, year
Thermal conductivity	λ	kJ/hr m K
Solar transmittance	T-sol	-
Visible transmittance	T-vis	-

CHAPTER 1

INTRODUCTION

Throughout history, the events and factors shaped the buildings. Currently, technology has changed the way of façade design with new developments in materials such as glazing type and way of management with new developments in control and computer technologies. Due to the increase in world population, the current buildings require more energy and consume more resources. This resulting in generating more pollution that drives the global environmental problems resulting in climate change. According to the report of Intergovernmental Panel on Climate Change (IPCC), the global surface temperature is to likely exceed 1.5°C by the end of the 21st century (IPCC, 2014), and one of the key findings was the necessity of "deep emissions reductions" to limit warming to 1.5°C, reaching net-zero CO_2 emissions globally by 2050 (IPCC, 2018). Buildings' role in responding to the climate crisis requires urgent actions to find out long-term solutions to mitigate these effects. This could be accomplished by several means in the building industry. To exemplify from the thesis perspective: (i) technology-focused measures such as the use of more energy-efficient systems and (ii) the application of passive design strategies to minimize building energy use. In this regard, IPCC (2018) stated that with the aim of reducing building emissions by 80–90% by 2050, new construction to be fossil-free and near-zero energy by 2020. Another important issue is the outbreak of the Covid-19 pandemic. The occupant health in buildings is an important topic in the academic world and building industry since people spend %90 of their time indoors (Klepeis et al., 2001). Thus, this current situation has affected the buildings. As such, to eliminate virus transmission risk in buildings, the ventilation of buildings became crucial. For example, in a recent study by Bhagat and Linden

(2020), the displacement ventilation that produces negative pressure at the occupant level was found to be an effective strategy to prevent the spread of the virus. Due to these emerging environmental concerns mentioned and the corona virus pandemic, the buildings have been challenged in terms of their design and strategies implemented for occupant satisfaction.

The developments in the research areas of Artificial Intelligence (AI) and the Internet of Things (IoT) enabling the connection between the virtual and physical environment have enhanced control technologies. This has led to the emergence of new terms, including intelligent buildings. The understanding of *intelligence* in the built environment has changed with the advancement of new technologies (Böke et al., 2019), and it is linked to the growth of Information Technology (IT) (Cho and Fellows, 2000). As a result, terms or adjectives have started to be used to describe the buildings, such as “smart,” “sustainable,” or “intelligent.” The focus of the thesis is on the notion of Intelligent Building (IB) which is widely studied in the academic community. The term “intelligent” is a buzzword used to strengthen its ability to think and make a rational decision and interpreted as doing everything automatically for the occupant comfort and energy efficiency. This attracts the occupants as a sign of quality. Thus, the term IB has been used in the industry, usually for advertisement purposes. However, although several studies exist about intelligent buildings in the academic literature, the IB concept evaluated differently. Some buildings were denoted as intelligent without meeting intelligence requirements (Zağpus, 2002). In the built environment, there is also a lack of common understanding of IBs among owners and developers of commercial buildings (Yang and Peng, 2001). Basically, they are being used for a type of built form that uses technology in the construction sector. Due to this, the IB concept is thought to be associated with a high-tech image representing a number of new technologies that enable automated operation and management. However, this conventional paradigm has been considered differently since intelligence is also related to intelligent design and architecture inspired by vernacular architecture in this thesis. This varying description of the IB leads to the divergent interpretation of its core idea during the design phase.

1.1 Problem Statement

The IB concept has different aspects and varying features in respond to occupant interest, goals of a particular company, and government. To meet the occupants' requirements, the buildings are designed in a unique way according to the climate conditions and available technology at the time. This explains the divergence in the interpretation of the concept of intelligence in buildings. Three main problems were identified within the scope of the thesis: (i) use of different terms/adjectives for buildings, (ii) use of the term *intelligence* for advertisement purposes without a clear description, and (iii) the balance between the application of passive measures and utilization of technology for building intelligence (iv) the complexity of existing building intelligence assessment tools.

Firstly, the term "intelligent building" (IB) has several definitions, and also intelligence has been denoted with several different notations. The reason for fuzziness around the term *IB* might be its common usage without knowing its meaning. An investigation of the literature revealed that there exist an ambiguity of the notion of IB since both the practitioners and researchers prefer to use varied expressions for buildings as "electronically enhanced" (Kroner, 1989; Kroner, 1997); "smart building" (Jia et al., 2018; Sinopoli, 2010; Buckman et al. (2014), "smart sustainable building" (Shaikh et al., 2014; To et al., 2018); "cybernetic building" (Bushby et al., 2001); "high performance building" (Lewis et al., 2010); "intelligent net zero- and positive-energy buildings" (Kolokotsa et al., 2011); "energy intelligent buildings" (Nguyen and Aiello, 2013); "green buildings" (Nguyen and Aiello, 2013); "sustainable intelligent building" (ALwaer and Clements-Croome, 2010); "energy-efficient building" (Chwieduk, 2003); "responsive building" (Clements-Croome, 1997). Same issue was also pointed out by Kroner (1997) that "smart" buildings, "high-tech" buildings, "integrated" buildings, and "advanced" buildings are under the umbrella of the current IB definition. In a similar vein, Ghaffarianhoseini et al. (2016a) stated that the terms, "sustainable," "green," "healthy," "digital," and "smart" in the areas of environmental, sociocultural, economic, and innovative dimensions are used interchangeably and all fall under a larger cluster called IB.

Researchers have put their effort into making a definition of the IB. In the literature, twenty-four definitions that focused mainly on occupant satisfaction, technology, and energy efficiency were found. Thus, it is obvious that the IB concept is interpreted differently when it is evaluated from different aspects. From a technology perspective, a researcher defined IB as a "cybernetic building" that uses BACnet technology to integrate various control systems and to connect the building systems to outside entities, such as utility providers (Bushby et al., 2001). The modern intelligent buildings are becoming cyber-physical ecosystems that live and breathe with their surroundings (Manic et al., 2016). Further, Jia et al. (2018) stated that they are emerging as complex cyber-physical systems with humans in the loop. As such, the true origin of the term was derived from AI (Wigginton and Harris, 2002). For instance, Dounis (2010) advocated that the application of AI technologies to buildings results in so-called “intelligent buildings.” The utilization of computer technology to govern the building autonomously (Sharples et al., 1999) and integration of advanced building technology systems (Sinopoli, 2010) were also highlighted in the earlier definitions. For the focus on energy efficiency, to resolve the global problems, a wider perspective was given by Clements-Croome (2011) and CABA (2008) that the IBs should be sustainable. To minimize the need to import energy is one of the aims of the IBs (Wigginton and Harris, 2002), and the goal of building technology is energy-saving (Nguyen and Aiello, 2013). Considering from occupant satisfaction perspective, an earlier definition for an office building was given by Hartkopft et al. (1997) that changing assemblies of recent technologies in appropriate physical, environmental and organizational settings to enhance worker effectiveness, communication and overall satisfaction. The adaptability to lifecycle circumstances changes for the occupants’ requirements (Chen, 2013; Clements-Croome, 2011) and communication with the occupant (Mofidi and Akbari, 2020) are depicted as the intelligent features of a building. These perspectives change and evolve throughout time and based on the location. Therefore, an official definition of the IB has not yet been standardized around the world (So et al., 1999); the definitions are very subjective in nature (So and Wong, 2002). Furthermore, there are different approaches regarding the assessment of building intelligence since the measurement of intelligence depends on how intelligence is defined (Harrison et al., 2012). In summary, the problem with the IB concept is the divergent interpretation of its meaning and loss of its main focus.

In general, the main interest in building design became building energy performance, which can be improved with active strategies, including improvement in HVAC systems, electrical lighting, or passive design strategies, such as improvements in building envelope elements (Sadineni et al., 2011). The advancement of the technology brought the feature of intelligent management and control of the buildings which helped the achievement of energy efficiency and creation of a healthy indoor environment. According to Cho and Fellows (2000), the controls enable to show the advantages of incorporating technological intelligence into the building. However, control strategy flaws may lead to high energy consumption (Chen et al., 2016). Also, how intelligent control exerts an impact on occupants' health, comfort and well-being should be questioned. It is frequently warranted in the literature that individual control by the user is the most crucial feature for occupant satisfaction. This issue is further discussed in Chapter 6. Thus, there is a common understanding that complex building management systems and the motorized or computerized control of active systems are a sign of intelligence. On the other hand, Ochoa and Capeluto (2008) stated that IB should be a product of the design process with passive features while taking advantage of technological innovations. Thus, the optimum balance of active systems achieved and passive design approach achieved raises the question of at what extent passive design strategies affects building intelligence.

In summary, in the academic community, the notion of IB was widely studied. However, there is no satisfactory consensus on the intelligent features and characteristics of the IBs. Moreover, the buildings are being advertised as more *intelligent* than others of their kind, although the meaning of that is not clearly explained in the industry. A novel approach for the IB concept for finding out a common ground and an evaluation methodology for the intelligence to support the designers for decision making at the conceptual stage of the project is needed. This thesis sets out to address this research gap.

1.2 Objectives and Research question

The main objective of this thesis is to contribute to the establishment of a commonly agreed approach to the IBs. Varying building users' profiles and requirements for each type of building, such as school, hospital buildings, and retail facilities, make it difficult to a general definition of an IB, and so, the main focus of the thesis lies on the offices. The office buildings are the ones mostly being advertised as *intelligent* to prove organizational success or enhancement of occupant health and productivity. Nevertheless, the given features and some approaches in this thesis could also be applicable to other building types.

The idea of intelligence in buildings improves with technological advancement in time. Hence, in this study, the current understanding of IBs is investigated. The intention is to find common ground for Intelligent Office Buildings (IOB) to draw state-of-the-art from the real-world buildings together with the collection of general understanding of industry practitioners and to explore the different aspects of the IBs in the literature. In this way, a general framework would be drawn to enable easy understanding and learning. Therefore, the aim is not to find a concrete definition of IOB, as it would become obsolete in an age of stunning technological advancement and changing occupant requirements. Rather, the intention is to identify the scope and boundaries of definition from the perspectives of designers and practitioners in the built environment and investigate the different aspects of the IBs. Furthermore, by exploring these aspects, the aim is to create a tool for the measurement of building intelligence.

In this regard, it is endeavored to answer the following research questions to find out what differentiates an IOB from a conventional one. This shall definitely result in a variant selection of materials and systems, and so, two central questions and related sub-questions were addressed:

RQ1. How is intelligent building defined and interpreted in the built environment?

- **a.** What is the impact of passive design approach and the utilization of active systems?
- **b.** What are the opposing perspectives in relation to building intelligence?

RQ2. What are the features that should be considered during their design and construction?

- **a.** What is the importance level of the features for *intelligence*?
- **b.** How the *intelligence* is measured for office buildings in terms of their features?

The first question was related to the search for the meaning of building intelligence in principle. The second question concerns the intelligent features compared to conventional ones since the IB comprises a broader range of functions. Finding out the answers to these questions will enable us to understand general questions of how IOBs should be designed and what features they should possess to be called *intelligent* in a better way.

1.3 Scope and Limitations

Searching answers to the research questions depicted in the previous section constitute the aim and scope of this study. As mentioned earlier, this thesis is concentrated on office buildings because of their marketability as *intelligent*. The IB concept touches on a variety of research disciplines such as Artificial Intelligence (AI), architecture, engineering, human intelligence, Internet of Things (IoT), and computational science for its design and operation. The literature on these fields is extensive. Thus, the information considered to be important is investigated only through the perspective of building intelligence. Accordingly, the details are mentioned in the relevant parts of the thesis to identify the definitions and terminology to enhance understanding of the IB concept.

The first question was explored by a detailed literature survey on the scope of IBs. The analysis of the studies put forward the diversity of understanding in terms of its expression with different terms and its interpretation from different aspects. Thus, the current understanding of the IB concept was questioned among building industry representatives via a survey. The survey was distributed to experts having experiences in different parts of the world. Having analyzed all the information obtained from the survey, the conflicting issues were addressed in the interpretation of the IB concept based on the collected experts' opinions and the findings from the literature studies. The conflicting issues are discussed in four separated groups, passive design with less technology; automated or occupant control; high technology or low technology and sustainability aspect by also comparing with the perceptions, ideas, and comments found in the literature. This is followed by a description of the IOB is made both in terms of its behavior and basic design principle.

The second question was asked to experts by presenting the integrated intelligent features extracted from literature and preliminary study results so that they are able to rate their level of significance with Likert scale in the survey. Contrary to the common belief that the IBs should be high-tech, a preliminary study was conducted to figure out the impact of the passive design approach and utilization of active systems on building energy consumption with thermal simulation steps. Using these features, an intelligence measurement framework is created. It provides a systems-thinking approach for intelligence during the very early design phase. All over the world, there are many voluntary assessment methods to evaluate buildings in terms of sustainability and intelligence. As summarized in the literature review chapter of the thesis, the existing schemes mostly evaluated within the framework of sustainability and its dimensions (i.e., economic, environmental, and social). In the construction industry, there is a common understanding for the indicators, such as energy efficiency and water efficiency, which are widely used for measurement in these tools. Thus, they are able to identify the issue without any short description of the application, and a cause-effect relationship is easily defined between the indicators and particular building performance. On the other hand, in this thesis, the proposed evaluation framework is different. Instead of using indicators, the assessment was made based on a set of features that make a building "intelligent" to eliminate the subjectivity of pre-defined indicators. The features also provided the specificity of regional properties for calibration. The features are evaluated in terms of their availability or degree of sophistication in terms of technology considered during the pre-design phase of the project. This tool would help the decision-making process during the pre-design phase by providing a body of knowledge for developers.

The main limitation is that the research outputs depend on the data collected. The experts' knowledge was collected through a survey that a limited number of practitioners attended. However, it could be said that the expert pool was quite representative, and the attendance from divergent nationalities revealed the approaches of varying cultures to the IB concept. It is worth noting that the extracted intelligent features from the literature are not directly considered. The ones measure environmental and economic dimensions, including non-monetary values, (e.g., cultural value, image value, and social value), are not included due to their variety based on country regulations and even political measures taken. A particular explanation of not including the environmental dimension that impacts the issues such as acidification, eutrophication and ozone layer depletion is that the energy resources that differ based on the location or country should also be considered for the calculation of gas emissions. This means that just reducing the heating and cooling load in a building scale would not be enough for the emissions calculations unless a life cycle assessment specific to the region is conducted. In line with this, the evaluation of economic and the financial viability of IBs investment with the used methodologies such as Net Present Value (NPV), cost-benefit analysis, Life Cycle Costing (LCC) are deliberately kept out of the scope of this research. The inclusion of those considerations also necessities tangible and intangible benefits of the IBs, which is hard to measure, and there is no cost information found in the literature. It is also because the economic evaluation mostly depends on local characteristics of the region and so varying from project to project. The main focus is restricted to only the availability of intelligent features. In other words, the approach for defining the features was to consider their attribution on the building intelligence. Nevertheless, the IB concept and its features introduced in this thesis indirectly impact social, economic, and environmental considerations. For example, the implementation of "the efficient use of resources" feature reduces the negative impact on the environment. The benefits of energy efficiency and enhanced occupant comfort bring additional savings to the consumption throughout the building life.

In conclusion, the difference in the definition of IBs in different parts of the world is clarified in terms of applied strategies and designers' preferences within the context of cultural and climate diversity. It is believed that the research outputs would pave the way for detailed discussions of experts on the IB concept and clarification of design concepts.

1.4 Research Methodology

Intelligence in buildings is a complex phenomenon having multidimensional aspects similar to the measurement of human IQ. Because the subject phenomenon being searched is relatively new and complex, mixed-method research entailing to study with quantitative and qualitative data was used. Among mixed methods research, the exploratory design: instrument development model is followed according to Creswell (2017). In this way, the qualitative data (the IB definitions and assessment frameworks) collected from the literature was used to develop a survey that enabled obtaining the quantitative data (i.e., the importance weights of the IB features).

The thesis is mainly split into three stages, and the methods for each are indicated in Figure 1.1. The stages are shortly summarized below and demonstrated in Figure 1.2, and their details are presented in the following chapters.

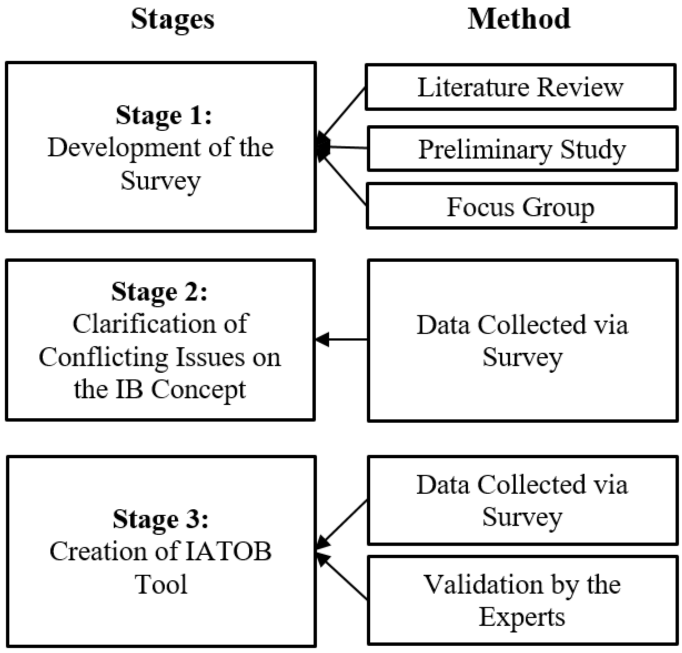

Figure 1.1. Research methods used for stages

Stage 1- Development of the survey (Chapter 3 and Chapter 4)

The first stage lays out the meaning of intelligence in buildings by exploring the approaches by previous researchers in the literature. In addition to the collection of experts' perceptions, based on the deep literature review, the quantitative part of the survey has been developed by combining a set of features of IB.

An extensive literature review was conducted by examining literature, specifically the books and journal articles published in this area, all of which are summarized in Chapter 2. Together with the definition and assessment methods of the IBs, all design components of intelligence in terms of technologies (building systems applied) and architectural considerations (passive design approaches) are searched. Thereafter, the papers were investigated in detail based on the content criteria: basically relevance and predominant characteristics of intelligence in buildings and number of citations of the found studies. After conducting the literature review, the importance of the passive design approach and the active system was evaluated as a preliminary study. A number of building energy simulation steps were followed to see the impact of façade design and building services. The simulation results have highlighted the importance of passive design for the IBs, and therefore, the features of "reduction of heating, cooling and ventilation load" and "application of natural/passive design strategies instead of active systems" were added into the survey as an intelligent feature. The details of this study are presented in Chapter 4. The survey was composed of two main parts to respond to the research questions: open-ended questions for collecting experts' perceptions on the IB concept and evaluation of the IB features in terms of their importance level. The IB features were extracted from the literature and preliminary study. They were analyzed and selected by using a conceptual construct approach in order to cover all critical aspects of the IB concept. Each feature was rated by a five-point Likert scale, and this has allowed deriving the quantitative measure for the importance level of each feature by asking an individual to make a qualitative assessment. As stated by Harpe (2015) that any phenomenon could be "quantified" through defining measurement scales. Before the distribution of the survey to all professionals, it was tested with a focus group with the purpose of clarity and content relevance of each feature. The survey was revised according to the feedback collected. Finally, the finalized version was distributed to building sector representatives in the built environment.

Stage 2 - Clarification of the conflicting issues regarding IB concept and the identification of the current approach to IOB concept (Chapter 6)

The second stage was studied based on the information collected through the survey. Responses to the open-ended questions, IB examples, and rated IB features were analyzed, and conflicting issues on the IB concept were discussed. As a result, a new approach to the IOB concept is provided by considering the current conditions of today's technology, occupant requirements, and potential solutions to environmental problems.

Stage 3 - Creation of a framework for the measurement of building intelligence (Chapter 7)

The consolidated typical intelligent features of office buildings were explored by visiting related literature. The importance weights of the features were identified as a result of a survey applied to experts in the building sector. A comprehensive framework of intelligence for office buildings, which considers all the relevant aspects of IOBs, is created.

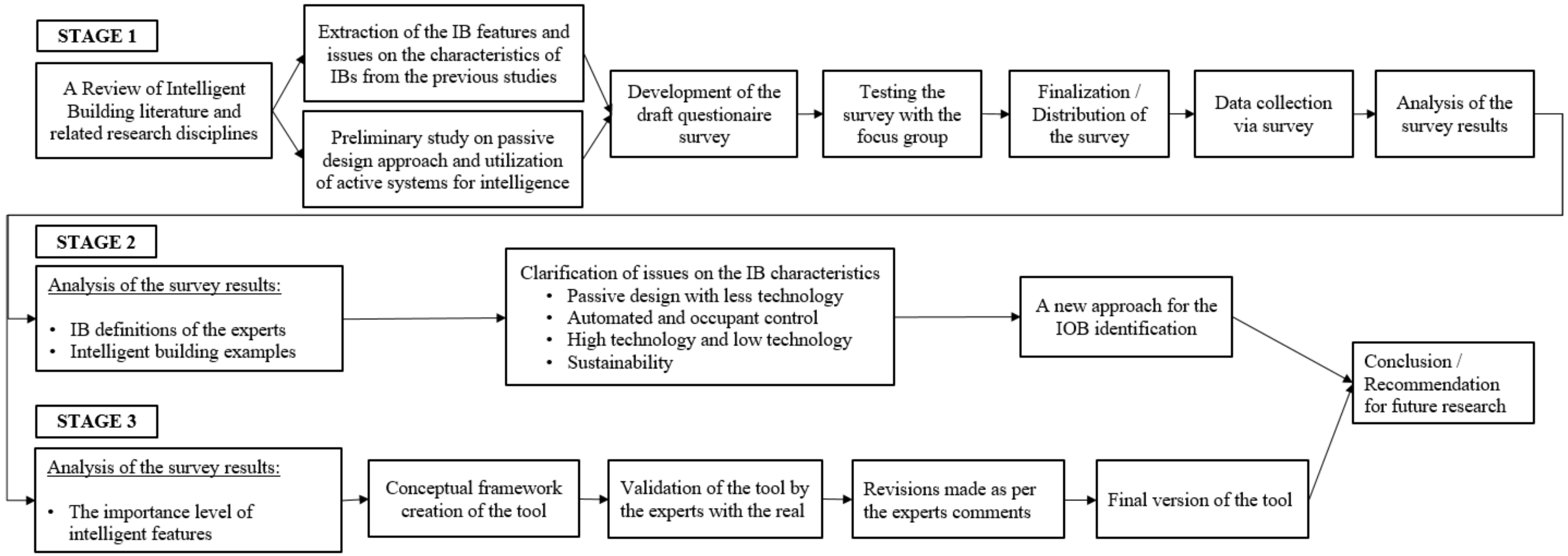

Figure 1.2. Research Design

1.5 Outline of the Thesis

The thesis is comprised of seven chapters; the content of each is summarized as follows:

Chapter 1 introduces the particular research field to be studied with the research questions by shortly describing the current problems with the IB concept and the methods by which the answers are sought.

Chapter 2 presents a short review in relation to specific areas related to science and technology within the building context. The explanation of the terms, which influenced the evolution of IBs shall facilitate an easy understanding of the ideas in the subsequent chapters. Furthermore, the existing definitions of IBs, meaning of intelligence from the literature sources, intelligent measurement tools, and frameworks available in the built environment are analyzed to find out the current gap in the literature.

Chapter 3 explains mainly the research methodology applied. The details of how the survey is developed and its content are presented.

Chapter 4 presents the preliminary study on the comparison of passive design approach and active systems to investigate their impact on the building energy consumption by a number of building energy simulation steps.

Chapter 5 presents the survey findings with the feature description of intelligent building examples.

Chapters 6 seeks to build upon some of the conflicting issues on the IB concept under four groups based on analyzed all the outputs of the survey. Then, a novel approach for the IOB concept is given in terms of its behavior and basic design principle.

Chapter 7 presents a tool prepared using Microsoft Excel for the measurement of the level of intelligence in office buildings which can be used during the pre-design phase. The tool introduces an intelligence measurement approach taking a set of features into consideration.

Chapter 8 summarizes each chapter and presents the theoretical and practical contributions of the thesis and concludes with recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

Initially, a literature review was performed on published journal articles and books on the IBs. The content-relevance and number of citations were the main criteria of the relevant academic article selection, and new studies from recent years were given importance during the study. Table 2.1 shows the keywords used for the literature study; in the first part, the concentration was on “definition of buildings with different characteristics,” which includes the papers studied on the various perspectives and building features whereas, the focus of the second part was on “the advancement and application of intelligence,” which includes the papers that primarily focused on the recent emergent research areas related with *intelligence*.

Table 2.1. Key words searched for literature study

Part 1 - Definition of buildings with different characteristics			
Intelligent Smart	Building Façade Design Architecture	Advanced	Building Technologies Building Systems
Part 2 - The advancement and application of intelligence			
Human intelligence			
Intelligent building performance measurement			
Cyber Physical Systems (CPS)			
Machine Learning (ML) application in buildings			
Passive design strategies			
Building Management System (BMS)			
Artificial Intelligence (AI)			
Internet of Things (IoT)			

While the results demonstrated the research diversity and continued evolution in the field of the IBs, what commonly found in the previous research efforts were the reviews and state-of-the-art in relation to IB definitions, advancement of building technologies, and the IB performance assessment methodologies. A broad area of research was conducted on the reviews of new technologies such as smart materials and active dynamic glazing and soft computing technologies (e.g., fuzzy systems and evolutionary algorithms). The information acquired from these sources only through the view of building scale is referred in this chapter.

In this framework, some definitions of the terms widely used in the area of IBs and some descriptions, especially utilized for the architectural and technological considerations, are provided in this chapter. Furthermore, the research topics related to occupant comfort conditions & behavior, sustainable buildings, building design, smart cities were shortly mentioned throughout the chapter considering their relationships to the IBs.

This chapter is structured in five sections, a summary review of literature charting the evolution of IBs are provided in terms of (i) the definition of the terms related to the IB concept; (ii) the efforts on the definition of IBs in the previous studies; (iii) the meaning of intelligence and the terms and research areas that influence the IB concept; (iv) the features of IBs; and (v) building intelligence performance evaluation methods of the IBs. Harmonizing all perspectives, preliminary study outputs, and technologies such as AI and IoT, research conclusions giving rise to the thesis research questions are drawn.

2.1 Building Design

Beginning of the section, it is better to give the statement by Wigginton and Harris (2002) that “a truly intelligent building has been intelligently designed as a prerequisite.” The design process is a complex part of the work with the inclusion of all stakeholders, designers from different professions, and even more manufacturers who influence the design with the advanced technologies in today’s world.

Therefore, the definitions of the design and architecture may be necessary to find out their connections to interpret and understand the underlying reasons of the IB design more easily. The first one is **the design method,** defined as a way of solving certain classes of problems: relating product with a situation to give satisfaction (Gregory, 1966). Secondly, **architecture** is the art above all others, which achieves a state of platonic grandeur, mathematical order, speculation, the perception of the harmony which lies in emotional relationships; this is the aim of architecture (Corbusier, 1970). Under the light of those, in previous studies, Kroner (1997) defined the reflections of **intelligent design** as responding to humanistic, cultural, and contextual issues, and earlier he stated exhibiting sustainability at both locally and globally and being in harmony with nature, rather than seeing the nature as an obstacle to be overcome (Kroner, 1989). In addition, the idea of intelligent architecture is expressed by Kroner (1989) with the following sentences:

> **"Intelligent architecture** is built form capable of anticipating and responding to phenomena (situations) external and internal to enclosed space which impacts the built form, occupants, and the biosphere. An intelligent architecture also provides the ways and means of managing whole-building performance, resource requirements, and outputs to provide a fully responsive environment to the ecology of the place as well as to the individual user."

An intrinsic part of the newly defined IB is the i**ntelligent façade,** according to Wigginton and Harris (2002). The building envelope or shell, consisting of walls, doors, windows, and foundation, is the main component to control the influence of the climate and thermal balance of the building. It serves as transferring light, solar radiation, air, noise, and moisture from the exterior and linking occupants to the outside world (Clements-Croome, 2011). Within the building industry, there is not a general understanding of the intelligent façade (Böke et al., 2019). The varying name of façades such as Kinetic Façade (Fortmeyer and Linn, 2014; Hosseini et al., 2019), Automated Adaptive Façade (Böke et al., 2020), Climate Adaptive Building Shell

(Loonen et al., 2013), and Intelligent Façade or Skin (Wigginton and Harris, 2002; Böke et al., 2019) have been used by the previous researchers.

In the literature, the façade intelligence means its adaptability with regard to internal and external circumstances (Böke et al., 2019); its ability to adapt to a variable environment by means of perception, reasoning, and action (Wyckmans, 2005). Intelligent facades are able to respond automatically by modifying their interior and exterior color and/or texture, changing their thermophysical properties, and changing their optical properties (Kroner, 1997). Moreover, referring as "intelligent skin," which is a part of a building system connected to other parts such as sensors and actuators with command wires, Wigginton and Harris (2002) described it as a weather-protecting zone, adjusting itself instinctively through self-regulated adjustments to respond predictably to environment variations in order to get maximum gain and minimal reliance on imported energy. This is also supported by the research of Wyckmans (2005) that the envelope's characteristics are listed as learning the occupant's preferences, selecting the most appropriate response for every situation with creating long-term strategies, anticipating the development of environmental conditions, and evaluating its own performance. Therefore, to accommodate the control of façade elements, the building shell should be designed to absorb IT applications (Loe, 1996). According to Wang (2010), intelligent façade can be centrally controlled while still providing the occupant an ability to manually override the system. It can change its thermophysical properties such as thermal resistance, transmittance, absorptance, permeability, etc; modify the interior and exterior colour and/or texture; function as communicating media façades with video and voice capabilities; change optical properties and allow the creation of patterned glazing, and provide an opportunity for dynamic shading and remote light control. The research area on the phase change ability of the façade is very wide taking also smart material technology into consideration. For instance, the integration of computation and sensing into the construction materials such as concrete and brick with the utilization of nanotechnology was studied by Adamatzky et al. (2020). Furthermore, in a review of glazing technologies, advanced glazings, and coatings (aerogels, antireflective coatings, self-cleaning glazing, photovoltaic glazing), smart glazing technologies were grouped into two as (i) passive glazing (thermochromic glazing, Phase Changing Materials (PCMs) based windows) that changes their properties when exposed to heat and (ii) active glazing (electrochromic glazing, gasochromic windows suspended particle, liquid crystal windows) that tunes optical properties by an external stimulus such as an electric field, heat or ion diffusion (Rezaei et al., 2017). Having these characteristics, the term "climate adaptive building shell" was defined by Loonen et al. (2013) as the ability to repeatedly and reversibly change some of its functions, features, or behavior over time in response to changing performance requirements with the aim of improving overall building performance.

Another aspect of the building design is the **adaptability**, three concepts of which were developed related solely to the physical design of buildings: generality (multifunctional use of its spaces and services), flexibility (built-in possibilities for rearrangement, take away or add elements/systems) and elasticity (the possibility of dividing functional units or extending in horizontal/vertical direction) are the abilities of a building to meet changing user and owner needs without changing its properties (generality), by changing its properties easily (flexibility) and to be extended or partitioned (elasticity) (Arge, 2005). Flexibility refers to the adaptability of a building's features to the needs of its users (Keymer, 2000), which means that accommodating to changes. In the thesis study, Keymer (2000) evaluated 20 projects in US and two projects in Europe, including all types of buildings such as office, residential, educational, and warehouses to collect design strategies for the design flexibility based on the expected changes for the short and medium-term which is less than 15 years and subsequent interview results indicated that there are ten clusters of 37 identified design strategies as reduce inter-system interactions, reduce intra-system interactions, use interchangeable system components, increase layout predictability, improve physical access, dedicate specific area/volume for system zone, enhance system access proximity, improve flow, phase system installation and simplify partial/phased demolition.

Passive Design is related to the design of the building's heating, cooling, lighting, and ventilation systems, relying on sunlight, wind, vegetation, and other naturally occurring resources on the building site, whereas **active or powered systems** is related with HVAC system (chillers, boilers, air handlers, pumps, and other powered equipment) (Kibert, 2016). Somewhat similar descriptions made by Bradshaw (2006) that active systems use outdoor collector panels to collect heat, and fans, pumps, and other mechanical equipment to transport it to and from an isolated storage unit, whereas passive systems collect and transport heat by nonmechanical means. The applied passive strategies are mostly the design of building envelope elements as reviewed by Sadineni et al. (2011) as walls (passive solar walls, double skin walls, etc.), fenestrations (aerogel glazing, vacuum glazing, switchable reflective glazing, etc.), roofs (masonry, lightweight, green, photovoltaic and evaporative roof cooling systems), types of thermal insulation, including phase change materials, thermal mass and air tightness of the building envelope. In the same vein, passive instructions are embodied in the building from (i.e., atria, shading devices) and active instructions occur in the spaces provided by the building (i.e., control interfaces, real-time monitoring, and display) (Brown et al., 2009). Energy-saving strategies applied in the passive houses (optimization of building envelope components, passive heating, and cooling techniques through climate factors, building orientation, and geometric ratios) are extensively studied and analyzed in the literature and proved to be the best applications for fighting against the climate change. The strategies applied in the Solar Decathlon Europe 2012 competition, as indicated in Figure 2.1, are passive strategies to avoid undesirable climate conditions such as solar radiation, wind, daylight, and thermal variability (Rodriguez-Ubinas et al., 2014). Given the benefits of these strategies, as the name implies, **Passive Houses** are buildings that provide comfortable indoor conditions at extremely low heating and cooling load, which is 75% to 95 % less compared to a traditionally insulated building with the same geometry (Schnieders et al., 2015). A dwelling design in Ankara indicated that 37% less energy consumption was achievable with an improved wall, which has a higher U-value compared to the requirements in standards, and 7.9% energy saving was gained with the optimum building orientation (Demirbilek et al., 2000). Ochoa and Capeluto (2008) compared passive features and active features for the climate of Haifa, Israel, which has warm summers and mild winters. After a number of simulation steps for the optimization of glazing type, orientation, blinds, lighting control, night ventilation, type of light shelf, the results indicated that using only intelligent technological devices (active features) did not yield the benefits of passive features.

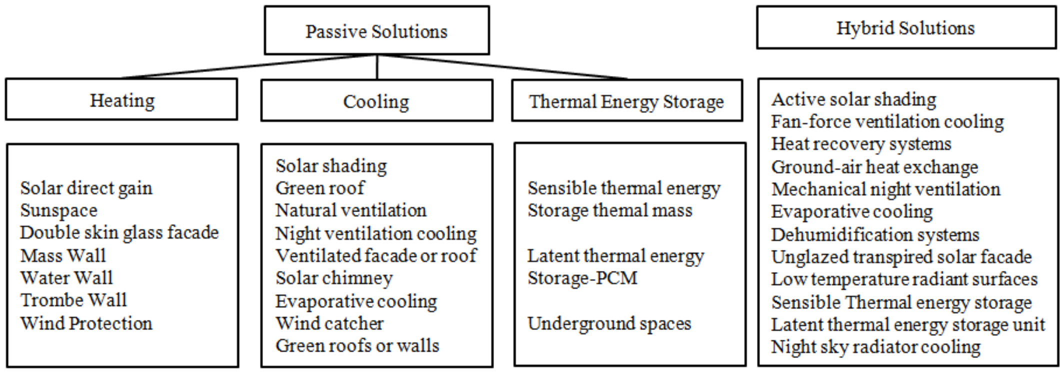

Figure 2.1. The list of summary for building passive design strategies
Source: Rodriguez-Ubinas et al. (2014)

Zero Energy Building (ZEB). Being a progression from sustainable passive design, a zero energy building refers to a building with a net energy consumption of zero over a typical year, meaning that the energy demand for heat and electrical power is reduced, and the remaining demand is generated from renewable energy systems integrated into the building or as part of a community renewable energy supply system (Wang et al., 2009). In the same vein, the European Commission (2010) directive mentioned that high energy performance building means near ZEB that requires a very low amount of energy which should be covered by energy from renewable sources, produced on-site or nearby. The idea of ZEB is the ability to meet the energy requirements from low-cost, locally available, nonpolluting, renewable sources (Torcellini, et al., 2006); based on two fundamental requirements, energy efficiency measures (for building envelope, services, and indoor conditions) and self-sufficient energy (renewable energy) (Belussi et al., 2019). Further, due to the interaction between the building and the grid, the term "Net Zero Energy Building (NZEB)" was mentioned; thereby, the balance among them are explained based on two major types of balance, namely the import/export balance and the load/generation (Sartori et al., 2012). The dynamic behavior of NZEB should be handled efficiently to balance the generation and consumed amount of energy (Kolokotsa et al., 2011), and 'two-way' flow should result in a net positive or zero export of power from the building to the grid (Wang et al., 2009). Hence, control and management strategies with real-time data became important.

Sustainable Building. Bell and Morse (2008) argued that it is dangerous to give a single definition to sustainability since the environmental, social, and economic conditions are different based on the location, and it changes with time and according to the perception of the onlookers.

As a sustainable building was drawn by Kohler (1999) in Figure 2.2 with the integration of three domains into a common framework where economic sustainability was related with the investment and the running costs; the social and cultural sustainability include comfort, wellbeing, and human health protection of the users and workers inside the building. In this regard, sustainable building means consciously using and introducing available resources, minimizing energy consumption, and preserving the environment (DGNB, 2021).

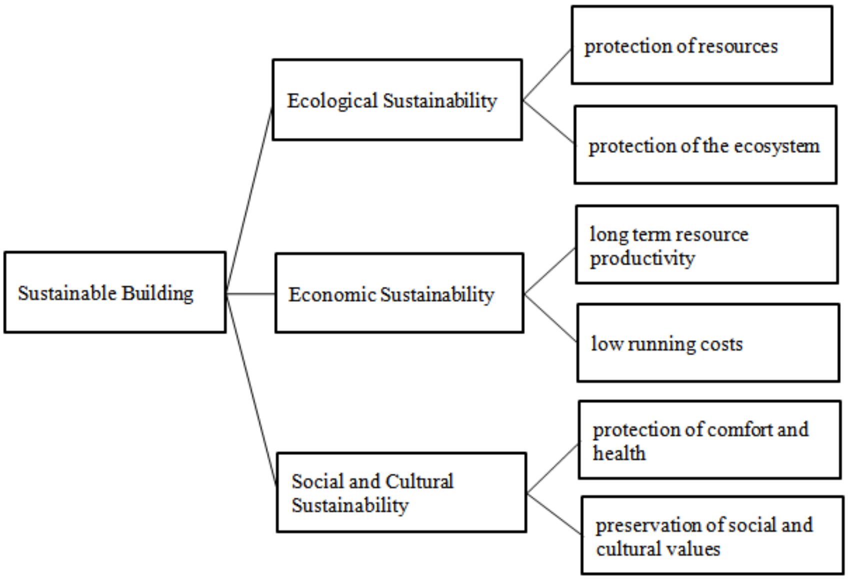

Figure 2.2. The three dimensions of sustainability and some associated goals for buildings.
Source: Kohler (1999)

Green Building. The notion of 'green' buildings is replaced by a larger concept of sustainable development (Kohler, 1999). Under the general term of `green building,' a whole new way of building performance assessment was proposed as Green Building Challenge (GBC) with three objectives, overcoming the shortcomings of existing environmental assessment tools, the integration of new performance issues (comfort, indoor air quality, longevity) and international coordination (Kohler, 1999). As a part of Green Building Challenge (GBC)' 98, the green strategies applied in Sweden are illustrated in Figure 2.3, which are natural ventilation with earth duct providing pre-heating of coming air, opening windows and solar chimney and getting benefit from the passive solar gain (Glaumann et al., 1999).

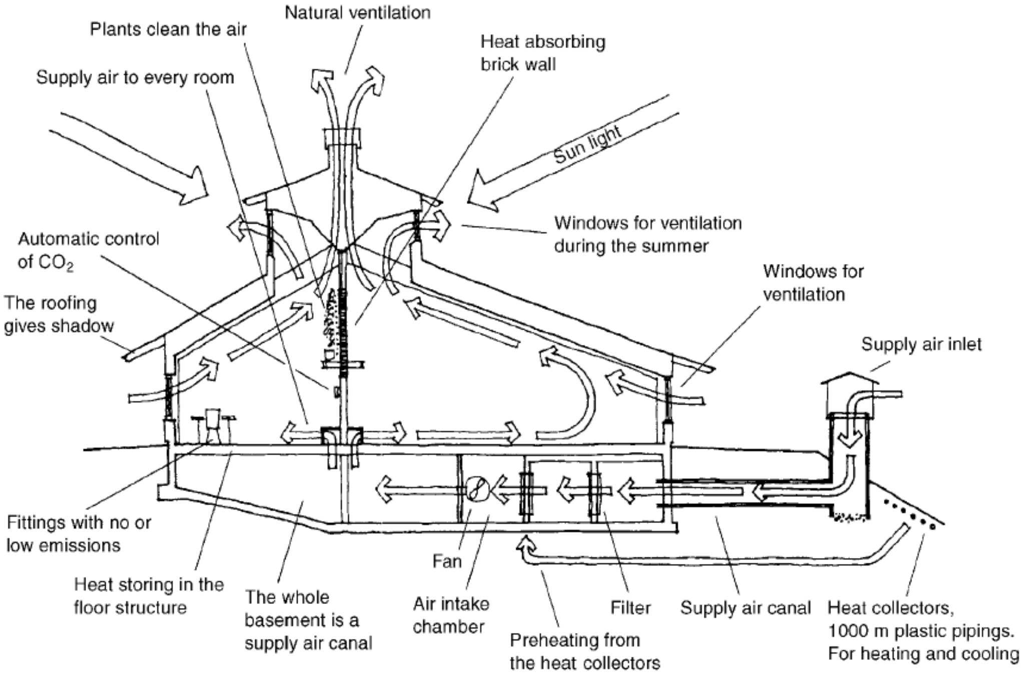

Figure 2.3. Green strategies applied in Sweden

Source: Glaumann et al. (1999)

2.2 Intelligent Building Concept in the Previous Studies

There are various views in the literature on what an intelligent building is or what makes a building intelligent. Therefore, in this part of the thesis, the IB concept in the earlier studies is presented from two perspectives: (i) the differentiation of its description in the world; (ii) its evolution in time.

The terms ‘intelligent’ and ‘smart’ concepts were analyzed in terms of their use in English, American and Russian dictionaries; it was revealed that even though they are used in the same sense, the word ‘intelligent’ relates to a higher level of development, than ‘smart’ (Taymanov and Sapozhnikova, 2014). The term “intelligent” has been used to express the ‘smart’ properties of the building system products (Wong and Li, 2009). According to Buckman et al. (2014), on the other hand, the term “smart” has been used interchangeably with “intelligent” without any clear distinction between the two.

First of all, some studies argued on the diversity of the IB definition based on the different regions of the world, specifically for Asia, South/North America, and Europe. The focus on the concept of IB varies in different countries, as summarized from the previous works:

- In *Europe*, zero energy (Ghaffarianhosseini, 2016), information technology/the genuine need of the user (So et al., 1999); the interaction between systems and the responsive structural elements (Arkin and Paciuk, 1997).
- In the *US,* performance, and cost-effectiveness (Ghaffarianhosseini, 2016); categorization of four basic elements, namely structure, systems, services and management and the interrelationship between them (So et al., 1999); the interconnection of service systems for the benefit of occupants (Arkin and Paciuk, 1997) and in *North America* advanced and innovative information technology (Ghaffarianhosseini, 2016).
- In *Southeast Asia, Malaysia and Singapore,* integration of the intelligent and sustainable design concepts and in *Singapore,* the automation and high-tech systems (Ghaffarianhosseini, 2016); in *Singapore and China*, "automation" with a great emphasis on high technology (So et al., 1999); in *Eastern Asia*, coexistence of smartness and sustainability embedded in the concept of IB and in *China,* the focus is on system aspects and automation while the focus is more service-oriented in *Japan* (Ghaffarianhosseini, 2016); in *Japan*, design according to the cultural considerations (So et al., 1999).

Secondly, multiple authors have worked on determining the overall meaning of the IB concept and examined the characteristics of the IBs that revealed a collection of 24 IB definitions from the exhaustive review list comprised of journal articles and books are presented chronologically in Table 2.2 with focus area expressed to indicate the change throughout the years. In approaching to define the IB, a number of focus areas were embraced during the evolution process: ***technology*** (Clements-Croome, 1997; Hartkopf, 1997; Sharples et al., 1999; Callaghan et al., 2001; Bushby et al., 2001; Wigginton and Harris, 2002; Kua and Lee, 2002; Zağpus, 2002; Dounis, 2010; Sinopoli, 2010; Chen, 2013; GhaffarianHoseini, 2013; Nguyen and Aiello, 2013; Ghayvat et al, 2015; Mofidi and Akbari, 2020); ***occupant satisfaction*** (Flax, 1991; Clements-Croome, 1997; Hartkopf, 1997; Arkin and Paciuk, 1997; So et al., 1999; Sharples et al., 1999; CABA, 2008; Clements-Croome, 2011; Chen, 2013; Buckman et al., 2014; Ghayvat et al, 2015; Jia et al., 2018); ***energy efficiency*** (Chen, 2013; Nguyen and Aiello, 2013; Buckman et al., 2014; Mofidi and Akbari, 2020); ***responsiveness*** (Clements-Croome, 2011; Chen, 2013; Wigginton and Harris, 2002); ***efficient resource management*** (Flax, 1991; Wigginton and Harris, 2002); ***sustainability*** (CABA, 2008; Clements-Croome, 2011); ***economy*** (Fathian and Akhavan, 2006); and ***passive design*** (Ochoa and Capeluto, 2008). Literature brief citing the interpretations for the IB concept are basically grouped into three categories: technology, occupant satisfaction, and energy efficiency.

Table 2.2. The previous definitions of the IBs

No	Year	Reference	Definition	Focus Area
1	1991	Flax	Intelligent building is one that creates an environment that maximizes the efficiency of the occupants of the building while at the same time allowing effective management of resources with minimum life-time costs.	Occupant satisfaction Efficient resource management
2	1997	Clements-Croome, D.J.	An intelligent building can be described as one that will provide for innovative and adaptable assemblies of technologies in appropriate physical, environmental and organizational settings, to enhance worker productivity, communication and overall satisfaction.	Technology Occupant satisfaction
3	1997	Hartkopf et al.	Intelligent office buildings will provide for unique and changing assemblies of recent technologies in appropriate physical, environmental and organizational settings, to enhance worker effectiveness, communication and overall satisfaction.	Technology Occupant satisfaction
4	1997	Arkin and Paciuk	The IB is a dynamic tool which can be used to create the personal, environmental, and technological conditions necessary for building occupants to maximize their individual capabilities, productivity, and satisfaction.	Occupant satisfaction
5	1999	So et al.	An intelligent building is designed and constructed based on appropriate selection of Quality Environment Modules to meet the users' requirements by mapping with the appropriate building facilities (termed elements within the IBI manual) to achieve long-term building value.	Occupant satisfaction

Table 2.2. The previous definitions of the IBs (continued)

No	Year	Reference	Definition	Focus Area
6	1999	Sharples et al.	An intelligent building is one that utilises computer technology to autonomously govern the building environment so as to optimise user comfort, energy-consumption, safety and monitoring-functions.	Technology Occupant satisfaction Energy efficiency
7	2001	Callaghan et al.	An intelligent-building works by taking inputs from building sensors (light, temperature, passive infra-red, etc.), and uses this to control effectors (heaters, lights, electronically-operated windows, etc.) throughout the building.	Technology
8	2001	Bushby et al.	A building that uses BACnet technology to integrate various control systems and to connect the building systems to outside entities, such as utility providers, is referred as a "cybernetic building."	Technology
9	2002	Wigginton and Harris	An intelligent building has the ability to know its configuration, anticipate the optimum dynamic response to prevailing environmental stimuli, and actuate the appropriate physical reaction in a predictable manner. It is expected that the system will strive to exploit the use of natural forces and minimize the need to import energy from non-renewable sources. The truly 'intelligent building' should therefore be endowed with some of the human characteristics that give it the ability to learn, adjust and respond instinctively to its immediate environment in order to provide comfortable internal conditions and use energy more efficiently.	Technology Efficient resource management Responsiveness

Table 2.2. The previous definitions of the IBs (continued)

No	Year	Reference	Definition	Focus Area
10	2002	Kua and Lee	An intelligent building can be defined as one that can support advanced hardware, such as the building and personnel management systems, as well as accommodate future technologies and the anticipated level of long-term user requirements.	Technology
11	2002	Zağpus	Intelligence in terms of buildings which is determined due to previously stated needs is described as; automatically managing ordinary works, in case of unexpected situations operating security system, able to establish communication between outside and inside users and electronic equipment with the help of software and automation systems.	Technology
12	2006	Fathian and Akhavan	Commonly, it is believed that intelligent buildings can help building owners and occupiers reduce operating and occupancy costs whilst providing an environment, which is more flexible, convenient, and comfortable for occupants. Further, such buildings offer advanced technological facilities together with reduced maintenance. Thus, those buildings offer improved operational effectiveness and efficiency and, so, enhanced marketability.	Economy Technology
13	2008	Ochoa and Capeluto	IB should be a product of design process with passive features while taking advantage of technological innovations.	Passive Design

Table 2.2. The previous definitions of the IBs (continued)

No	Year	Reference	Definition	Focus Area
14	2008	CABA	A building that uses both technology and process to create a facility that is safe, healthy and comfortable and enables productivity and wellbeing for its occupants and exhibits key attributes of environmental sustainability to benefit present and future generations.	Occupant satisfaction Sustainability
15	2010	Dounis	Application of AI technologies to buildings results in so-called "intelligent buildings".	Technology
16	2010	Sinopoli	A smart building involves the installation and use of advanced and integrated building technology systems, including building automation, life safety, telecommunications, user systems, and facility management systems.	Technology
17	2011	Clements-Croome	Intelligent buildings need to be sustainable (i.e., sustain their performance for future generations), healthy and technologically up to date; meet regulatory demands; meet the needs of the occupants, and be flexible and adaptable enough to deal with change.	Sustainability Technology Occupant satisfaction
18	2013	Chen Z.	The intelligence of a facility can be defined as the designed capacity of a facility to acquire and process data and information to perform its adaptability to lifecycle circumstance changes in terms of people's requirements of wellbeing and energy efficiency.	Technology Energy efficiency Occupant satisfaction
19	2013	GhaffarianHoseini et al.	Basically, the concept of a smart house focuses on two constituents: it has to be fully integrated with ambient intelligence environments, and it has to base on the interrelations between the users and environments.	Technology

Table 2.2. The previous definitions of the IBs (continued)

No	Year	Reference	Definition	Focus Area
20	2013	Nguyen and Aiello	Energy intelligent buildings' refers to buildings equipped with technology that allows monitoring of their occupants and/or facilities designed to automate and optimize control of appliances, in particular, lights, HVAC system, and home appliances, with the goal of saving energy.	Technology Energy efficiency
21	2014	Buckman et al.	The buildings which integrate and account for intelligence, enterprise, control and materials and construction as an entire building system, with adaptability; not reactivity, at its core, in order to meet the drivers for building progression: energy and efficiency, longevity and comfort and satisfaction.	Adaptability Energy efficiency Occupant satisfaction
22	2015	Ghayvat et al.	The word 'smart home' is preferred for a home environment equipped with advanced technology that allows monitoring and control of its inhabitants, and boosts independent living through wellness forecasting based on behavioral pattern generation and detection.	Technology Occupant satisfaction
23	2018	Jia et al.	Smart buildings today are aimed at providing safe, healthy, comfortable, affordable, and beautiful spaces in a carbon and energy-efficient way. They are emerging as complex cyber–physical systems with humans in the loop.	Occupant satisfaction Energy efficiency
24	2020	Mofidi and Akbari	An intelligent building should (1) perceive its environment through indoor environment monitoring system; (2) communicate with occupants and know their needs; (3) make energy-related decisions by its energy management system (EMS); (4) take energy-related actions through its energy management and control systems (EMCS), (5) have a learning capability to improve its performance, and (6) have a proper communication to the grid.	Technology Energy efficiency Occupant satisfaction

In the mid-1980s, the word ‘intelligent’ was originated and used with the American term “smart” for implication of the same kind of abilities in materials, structures and buildings at the beginning of the 1980s and the Hartford building in the USA was heralded as the first intelligent building in the world (Wigginton and Harris, 2002). During the 1980s, the concept of IB was basically linked to the growth of information technology with sophisticated telecommunications, building management, and data networking services for the shared tenant services (STS) (Harrison et al., 2012). The notion of IB was described as ‘a new generation of buildings that almost think for themselves…’ by New York real estate developers in 1984 (Sinopoli, 2010). The IBs were described with sophisticated telecommunications, building management, and data-networking services; however, Orbit research (Orbit-1 and Orbit-2) set for the examination of the interaction between the organization, building, and information technology added a new perspective to this technology-based concept as being responsive to change (Harrison, 1992).

In 1990s, the IB concept has expanded with the inclusion of a cohesive linkage between “users, building systems, environment and quality of life” in 1990s (Ghaffarianhoseini et al., 2016a). As seen in all of the definitions of this period, there is always a primary concern in the building design, human being. Given the international definitions, So et al. (1999) provided a new definition for Asia by highlighting the importance of design based on users' needs instead of the image of the building itself. The evolution of the IB was divided into three periods: (i) the period of 1981-1985 named as “Automated Buildings” with the features of building management, office automation, and communications; (ii) the period of 1986-1991 named as “Responsive Buildings” with the ability to be responsive to the changes; (iii) the periods of 1991-present named as “Effective Buildings” with the definition of “any building which provides a responsive, effective and supportive environment with which the organization can achieve its business objectives” (DEWG and Technibank,1992). In the final definition, business management and space management are included in the IB concept. In those years, the buildings that contained IB technologies and building systems were named “electronically enhanced" (Kroner, 1989). The building intelligence was highly related to the system integration (Arkin and Paciuk, 1997), and *intelligence* in buildings implied facilities management via building automation systems (BAS) (Loveday, 1997). Thus, the computer science definition was proposed by Sharples (1999) and Callaghan et al. (2000). This is also expressed by Flax (1991) intelligent building systems should be controlled through a single control framework so that they can respond to their environment in a timely and cost-efficient manner. Then, the progression of the IBs moved from being thought of as a collection of innovative technologies via responsiveness to being a facility for business activities (Cho and Fellows, 2000). Harrison (1992) described the IBs in a European context by three main goals of an organization: building management (environmental control of the building, user access to environmental systems); space management (management of change, the minimization of operating costs), and business management (the processing, storage, presentation and communication of information). In the Asian context, the definition made by So et al. (1999) includes two dimensions, i.e., the needs of the building developer/owners/occupants (deliverable items) and the enabling technologies (systems and services). The same definition was repeated in 2002 (So and Wong, 2002). In short, during this period, the definition was purely related to the technology used to enhance stakeholder satisfaction productivity as the similar definition presented by Clements-Croome (1997) and Hartkopf et al. (1997).

Between 2000 – 2010, the two significant differences in definitions for this period, compared to the previously mentioned definitions, were the use of BMS and the significance of passive design. The IB, expressed as another type of modern energy-efficient buildings was named from the intelligent BMS, controlling all systems for the proper energy management and the improvement of the comfort levels and increasing the building's productivity through leveraging information (Chwieduk, 2003). Likewise, in a thesis study by Zağpus (2002), one of the professionals stated that the IBs are those that are being operated by different BAS and also whose systems could communicate to others at the center. In contrast, Ochoa and Capeluto (2008) offered a somewhat different definition that IB should be a product of the design process with passive features while taking advantage of technological innovations. Perhaps the definition of IB was expressed more clearly in the work of Wigginton and Harris (2002) during this period. Their work was related to intelligent skin by providing the meaning of intelligence, intelligent building, and intelligent skin with the presentation of case buildings. Moreover, a number of institutions offered varying definitions. The European Intelligent Building Group considered the IB as incorporating the best available concepts, materials, systems, and technologies to meet performance requirements of the building stakeholders, such as building owners, users, and the local and global community (Wigginton and Harris, 2002). On the other hand, the Asian Institute of Intelligent Buildings (AIIB) made an official definition of the IB, "An Intelligent Building is designed and constructed based on an appropriate selection of Quality Environment Modules to meet the User's Requirements by mapping with the appropriate building facilities to achieve a Long-Term Building Value" (Chow and Leung, 2005). The same definition was made earlier by So et al. (1999).

Another aspect for this period as the versatile studies (the Continental Automated Buildings Association (CABA), 2008; Katz and Skopek, 2009 and Sinopoli, 2010) put forward was the concept of "bright green" that can be achieved using intelligent technology to provide a tangible and significant return on investment. This is the indication (Figure 2.4) of the overlap between green and intelligent buildings both in their design and construction practices (Cole and Brown, 2009).

2010 to present: The concept and perception of the IBs have been extended to sustainability in the built environment together with the importance of energy efficiency. Clements-Croome (2011) defined the IBs as "sustainable intelligent buildings"; Ghaffarianhoseini et al. (2016a) highlighted the importance of sustainable design; Kua and Lee (2002) stated that the IBs should be used to promote ecological, economic and social-cultural sustainability; Arditi et al. (2015) pointed out that smartness is a part of the sustainability movement. Therefore, the concepts related to the IBs are similar to the ones in sustainable buildings (ALwaer and

Clements-Croome, 2010). Tetik (2014) proved the significance of the passive design approach rather than only just technological active systems.

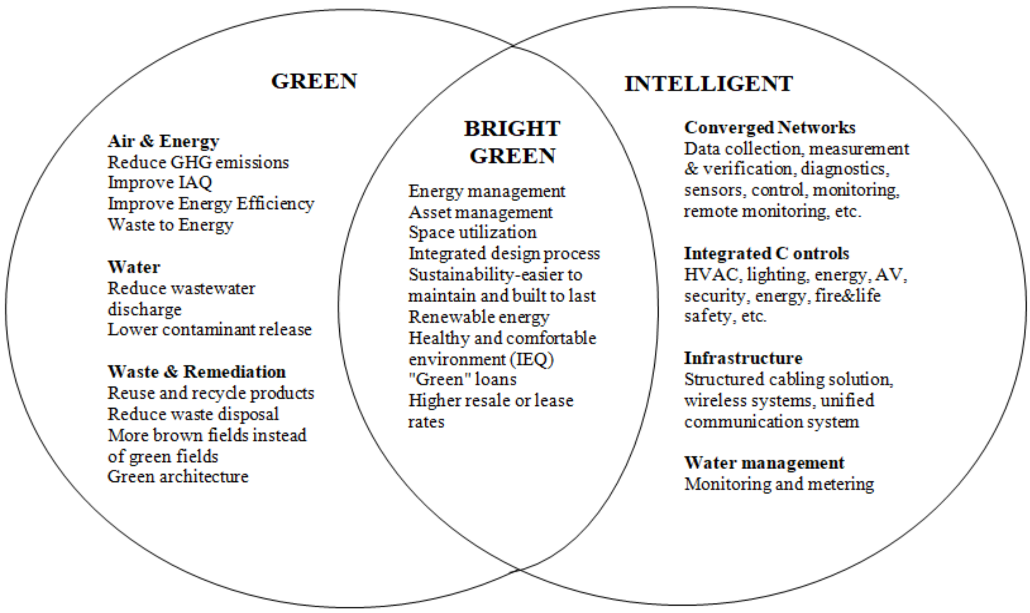

Figure 2.4. Convergence of Intelligent and Green Buildings
Source: Continental Automated Buildings Association (CABA) (2008)

Emerged during the 2000s, another terminology, smart buildings, is included in the scope of this thesis. Especially, the ones that discussed the difference between the IBs and smart buildings were included to understand the distinction between these two terms throughout the views of other researchers. Having expressed by Buckman et al. (2014), four features/pillars of smart buildings are (1) the methods by which building operation information is gathered and responded to (intelligence); (2) the interaction between the occupants and the building (control); (3) the buildings physical form (materials and construction); and (4) the methods by which building use information is collected and used to improve occupant performance (enterprise) and adaptability being prepared for a particular event before the event has happened by the utilization of gathered information is at the heart of the definition. Therefore, the clear difference between smart and intelligence of buildings was highlighted as the IBs are generally reactive whereas smart buildings are adaptive. De Paola et al.

(2019) suggested hybrid intelligence by defining reactive intelligence for quick adaptation to the ever-changing environment and deliberative intelligence for performing complex learning and optimization, and such hybrid nature enabled both reactions to the event in real-time and improvement by learning users' needs simultaneously. Mofidi and Akbari (2020) highlighted the importance of intelligent control of building facilities and the establishment of continuous communication with occupants, together with self-learning ability for the energy-related occupant behavior as well.

The review studies in the literature, Wong et al. (2005) classified the existing literature of the IBs in terms of three research aspects, advanced and innovative intelligent technologies research, performance evaluation methodologies, and investment evaluation analysis. More recently, Mofidi and Akbari (2020) reviewed the existing studies on occupant comfort conditions, productivity, behavior modeling, building control, computational optimization, and environmental monitoring and analysis in order to discuss the conflict between reducing energy consumption and improving occupant comfort conditions.

Having considered the information above, the literature review raises the question of: is there a current understanding of the IB concept agreed upon in the built environment? Or, how could we interpret the building intelligence after 2020s?

2.3 The Meaning of Intelligence

The basis for the development of true intelligence was provided by mobility, acute vision, and the ability to carry out survival related tasks in a dynamic environment, according to Brooks (1999). The intelligence concept became much broader with the advances in the research areas of AI, including fuzzy logic, neural networks, evolutionary computation, and related reasoning techniques (Bien et al., 2002). This study encountered a plethora of research issues and challenges in the field of AI or cybernetics, which is a branch of computer science (Dounis, 2010), the IoT, sensor networks, and integration of sensors with the internet, which is wireless sensor networks (WSN). Cybernetics is described because one of the researchers (Bushby et al., 2001) defined a building by referring as a "cybernetic building." Furthermore, mainly the developments in these research areas have resulted in changing how the buildings are managed/monitored and the intelligent features of buildings, such as real-time data collection, modeling the occupant behavior and preferences, self-adjustment of building systems. The following sections of this chapter start with the meaning of intelligence and then present these research areas and how the advancements in these fields have potentially influenced building design.

The meaning of intelligence in the dictionary - Intelligence is defined in the dictionaries as "the ability to learn or understand or deal with new or trying situations" (Merriam-Webster, n.d.) "the ability to learn, understand and think in a logical way about things; the ability to do this well" (Oxford, n.d.). Furthermore, as Taymanov and Sapozhnikova (2014) put it, "an ability to perceive, analyze, accumulate and transit information." The word 'intelligence' is explained in the book of Pfeifer and Scheier (2001), in which common sense notions of intelligent beings are given as thinking and problem solving; the competence to speak, read and write; intuition and creativity; learning and memory; emotions; surviving in a complex world; and consciousness.

Human Intelligence - Intelligence has always been questioned and searched throughout history, especially how we think, perceive, understand, predict and manipulate (Russell and Norvig, 2010) and finally, the ability to make a decision based on the evaluation of existing situations or problems. Human beings were considered within the sense-think-act cycle: information processing systems that perceive input from the environment (perception), a process that information (thinking), and act upon the decision reached (behavior) (Pfeifer and Scheier, 2001). It is a fact that *intelligence* is the main ability for the survival of human beings during the evolution process, which is basically adaptation to the changing environment. Brooks (1999) stated that the essence of being is to achieve the requirements of life to maintain and reproduce by moving around and sensing the surroundings, and this part of intelligence depended on the evolution time.

The definition of human intelligence agreed by 52 researchers: "*Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings-"catching on," "making sense" of things, or "figuring out" what to do*" (Gottfredson, 1997). Even though we have a little understanding of how intelligence develops, it is obvious that "*intelligence is a combination of the ability to "figure things out on the spot" and the ability to retain and repeat things that have been figured out in the past*" (Deary et al., 2010).

Nature Intelligence - Natural intelligence is observed all around us, and this may be expressed with the words of Corbusier (1970) as "*the objects in nature and the results of calculation clearly and cleanly formed; they are organized without ambiguity*." Nature has already solved many mechanical and structural problems humans face today without generating residual, inactive waste (Royall, 2010). Under this topic, the term "biomimicry" originated from the Greek words bios, meaning "life," and mimesis, meaning "to imitate," which searches for solutions to human problems in nature (Benyus, 2002). As such, the knowledge from bio-inspired concepts can be used in today's architecture and main technological areas, (1) new materials, (2) constructions, (3) surfaces, (4) adhesives and bonding technology, (5) optics and photonics; that will improve performance of future buildings (Gorb and Gorb, 2020). In building design, the architecture of insects building structures (their homes) gives us important lessons with the diversity of form, material, and function to resolve the ecological challenges in their nest environments, and the knowledge of their construction behaviors are being used for computational modeling (Sane et al., 2020). The concept of biomimetic actuators for the architecture is generated from the mobile plant structures and their movement principles (e.g., leaves, petals, cone scales, and capsules) (Poppinga et al., 2018). The plants like buildings have a lack of movement and remain at a specific location, have special means of protection and adaptation against the changing outside conditions such as darkness, light, humidity, rainwater, fire, temperature, freezing, air movement, or air quality (López, et al., 2017). Considering the inspiration from the human body, some researchers stated that the building façade should be adaptive and active similar to the human skin (Fortmeyer and Linn, 2014); the intelligent skin having pseudo-autonomic abilities like the human body, which do not require conscious control, such as the actions of the iris of the eye (Wigginton and Harris, 2002). In this regard, López, et al. (2017) provided a review of advances in adaptive architectural envelopes, including those based on biomimetic principles (built projects and academic research works).

Machine Intelligence - Bien et al. (2002) defined four intelligent attributes of system intelligence: autonomy, controllability for complicated dynamics, human-machine interaction, and bio-inspired behavior-based technology, as shown in Figure 2.5. Those attributes support improved safety, enhanced reliability, high efficiency, and economical maintenance.

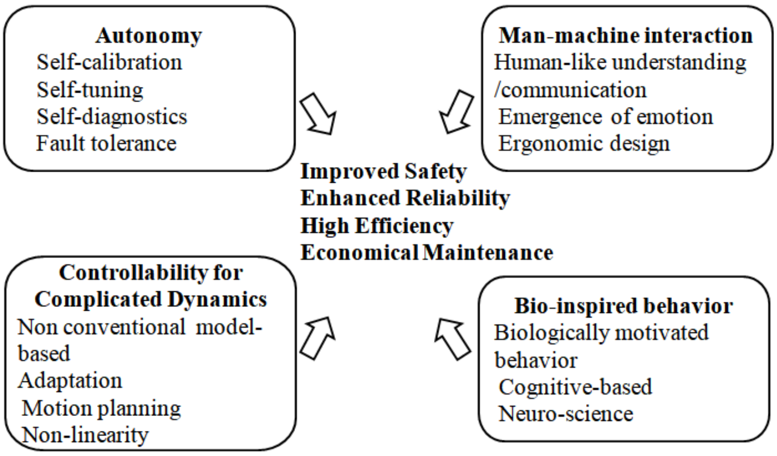

Figure 2.5. Grouping of key attributes in intelligent systems

Source: Bien et al. (2002)

Artificial intelligence (AI) started as a field with the purpose of human level intelligence replication in a machine, according to Brooks (1999); hence, it attempted not just to understand but also to build intelligent entities (Russell and Norvig, 2010). This field has enabled to mimic human capacity to process information by learning, inferring, making, and acting on decisions (Wigginton and Harris, 2002). The definitions of AI, one of the newest fields in science and engineering, are tabulated by Russell and Norvig (2010). As seen from the table, the thought process and reasoning definitions called “thinking” are given on the top row, whereas definitions related to behaviors called “acting” are provided at the bottom row. Moreover, the definitions are categorized into two columns, the measures with respect to human performance and ideal performance called “rationality” (Table 2.3).

Table 2.3. Some definitions of artificial intelligence, organized into four categories
Source: Russell and Norvig (2010)

Thinking Humanly	**Thinking Rationally**
“The exciting new effort to make computers think . . . *machines with minds,* in the full and literal sense.” (Haugeland, 1985) “[The automation of] activities that we associate with human thinking, activities such as decision-making, problem-solving, learning . . .” (Bellman, 1978)	“The study of mental faculties through the use of computational models.” (Charniak and McDermott, 1985) “The study of the computations that make it possible to perceive, reason, and act.” (Winston, 1992)
Acting Humanly	**Acting Rationally**
“The art of creating machines that perform functions that require intelligence when performed by people.” (Kurzweil, 1990) “The study of how to make computers do things at which, at the moment, people are better.” (Rich and Knight, 1991)	“Computational Intelligence is the study of the design of intelligent agents.” (Poole *et al.*, 1998) “AI . . . is concerned with intelligent behavior in artifacts.” (Nilsson, 1998)

The research and development in the area of AI prevail *intelligence* of buildings in terms of both architectural design and building systems. AI embedded into the IBs enables the adaptability to external environment by learning from users and monitoring its functionality in terms of assets, space and energy (Serrano, 2020). The application of AI can be seen in advanced building systems, such as smart/energy-efficient lift systems. With AI techniques, the identification of passenger numbers and traffic patterns with the existence of supervisory control algorithms is possible (Wong et al., 2008). AI techniques supported by standard communication protocols such as Ethernet, BACnet, and Internet enable the interchange of information and collaboration between the intelligent agents to achieve the main goals, such as energy efficiency, comfort, health, and productivity in living spaces in the IBs (Dounis, 2010). A complete agent that could be humans, animals, or robots was described as autonomous, embodied, situated, and self-sufficient (Pfeifer and Scheier, 2001).

The basic idea of IoT concept is "the pervasive presence around us of a variety of things or objects – such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc. – which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals" (Atzori et al., 2010). In a communicating–actuating network, the IoT, wherein sensors and actuators blended seamlessly with the environment around us and enabled to share information across platforms (Gubbi et al., 2013). Furthermore, Atzori et al. (2010) explained the IoT paradigm with the convergence of three main visions, "internet-oriented" being a network-oriented; "things oriented" focusing on objects to be integrated into a common framework; "semantic oriented" addressing of the object and representation and storing of exchanged information. Also, Arsénio et al. (2014) mentioned the paradigm of the IoIT (Internet of intelligent things) communicating with each other and people going beyond the IoT.

The advancements in the fields of Micro-Electro-Mechanical Systems (MEMS) technology, wireless communications, and digital electronics emerged the sensor nodes which are low-cost, low power, small and ability of wireless communication and then a large number of nodes brought the idea of **sensor networks** which has very different application areas, such as military, environmental, health, and home (Akyildiz et al., 2012). Utilization of IoT technology in building automation, objects, and materials are interconnected with a wireless network, which enables the gathering of real-time data in Ambient Intelligence environments (Arsénio et al., 2014). The digital (cyber) environment created with the incorporation of AI techniques/methods and thousands of embedded and mobile devices to perceive the presence/behavior of users and adapt accordingly is called **Ambient Intelligence** (AmI) (Dounis, 2010). The research of AmI builds upon advances in sensors and sensor networks, pervasive computing, and AI (Cook et al., 2009). The terms for devices are defined in the study of Taymanov and Sapozhnikova (2014): *an element of a measuring or control instrument, which is directly affected by a phenomenon, body, or substance carrying a quantity to be measured* as a sensor; *a sensor device capable of interacting with other devices on the basis of processing the data received* as a smart sensor device, the simplest feature of intelligence; a sensor device with a self-check function as an intelligent sensor device. Figure 2.6 illustrates how the building (ambient intelligence environment) interacts with its users and its surrounding environment to produce the automatic action given back to the building (Ramos et al., 2008).

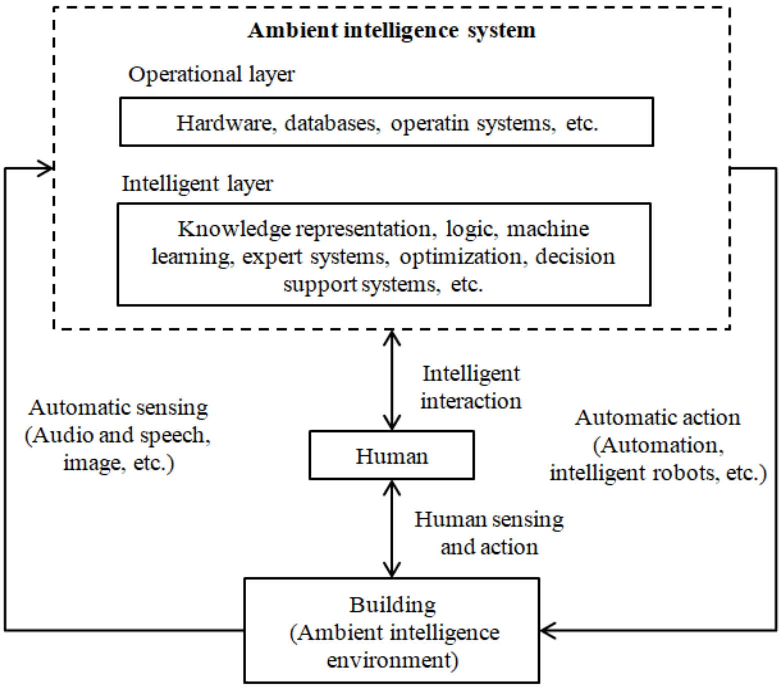

Figure 2.6. The ambient-intelligence vision from an artificial intelligence perspective
Source: Ramos et al. (2008)

The features of AmI technologies are sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent; the devices in a smart home enriched with sensors, such as electrodomestics (e.g., cooker), household items (e.g., taps), and temperature handling devices (e.g., radiators), accrue the benefits pertinent to building safety (e.g., prevention of a possibly harmful situation), occupant comfort (e.g., auto-adjustment of temperature) and economy (e.g., control of the use of lights) (Cook et al., 2009).

The IoT observes and also actuate in the real world (Arsénio et al., 2014) and so, IoT systems consist of five components as 1) Devices or Sensors (terminal), 2) Networks (communication infrastructure), 3) Cloud (data repository and data processing infrastructure), 4) Analytics (computational and data mining algorithm), and 5) Actuators or User interfaces (services) (Jia et al., 2019). The internet morphing into the IoT, embraces many technologies and services and connects the appliances, such as mobile phones, Global Positioning System (GPS); further, it shall expand the house appliances, also including electricity, gas and water meters and smart grid, for example, being one of the important applications of IoT (Hersent et al., 2012). With the advancement in internet technologies and WSN, a new trend of ubiquity is being realized (Kelly et al., 2013). One of the significant developments in WSN-based smart homes is the injection of IoTs which enabled remote monitoring and control (Ghayvat et al., 2015). For example, through the IoT website, the monitoring of regular domestic conditions of the building such as solar water heating system, electrical household appliances, and room temperature with real-time graphical illustration was achieved by 97% reliability (Kelly et al., 2013). In the same vein, the real-time monitoring via sensor networks of the electrical appliances such as room heaters, microwave, oven, toasters, water kettle, fridge, television, audio device, battery charges and water pump were tested at an elderly home to lower the electricity consumption and find a saving solution during the daily peak hours (Suryadevar et al., 2015). An overview by Jia et al. (2019) summarized the IoT applications in a smart home: localization for occupants and resource tracking, energy management, facility management, indoor comfort enhancement, and occupant safety and health security. By way of a specific example, Luo et al. (2009) developed a multi-sensor based intelligent security robot for an intelligent building that is able to transmit the information to the client's computer through the internet when abnormal and dangerous situations, such as fire and intruder are detected and notify users by sending a message to their cell phones.

The terms "Internet of things" and "Artificial Intelligence" allowed the connection of computer world with the real world. This brought another general term, **"Cybernetics,"** which enables *the interaction between human and machine and between machines amongst each other* (Böke et al., 2019) and is defined as the science of control and communication of complex systems (Bushby et al., 2001). The **Cyber-Physical System (CPS**) *is a term describing a broad range of complex, multi-disciplinary, physically-aware next-generation engineered system that integrates embedded computing technologies (cyber part) into the physical world* (Gunes et al., 2014); *is integrations of computation with physical processes* (Lee, 2008).

A cybernetic building system involves energy management, fire detection, security, and transport systems and interactions with outside service providers, utilities, load aggregators, and emergency services (Bushby et al., 2001). The smart grid connection, which is a part of the smart city concept, became a necessity for the IBs (Gunes et al., 2014). A smart grid accommodates a wide variety of generation options, e.g., central, distributed, intermittent, and mobile (Farhangi, 2010) and integrates the behavior and actions of all users connected to it, e.g., generators, customers for sustainable supplies (Yu et al., 2011); enables the smart buildings to perform load reduction and peak shaving (reducing demand for electricity during peak usage times) and load shifting, and can reduce blackouts (total loss of power) and brownouts (voltage drops) (Manic et al., 2016). On the other hand, the smart city has a multifaceted meaning (Albino et al., 2015) and is described based on three foundations as *instrumented* (real-time data collection from the physical world); *interconnected* (utilization of collected data in a computing platform, and sharing the information with the city services) and *intelligent* (complex analytics, modeling, optimization, and visualization for the better operational decisions in the business process) (Harrison et al., 2010). The cities Hamburg, Nantes, and Helsinki are understudies to make sustainable cities with smart people and smart economy by digitalization (EU mySMARTlife Consortium, 2021). Vrba et al. (2014) envisioned the future smart grids as a distributed ecosystem with a number of components communicating both the electricity and information level.

Due to the unpredictability of real-world cyber-physical systems must be robust to unexpected conditions and adaptable to subsystem failures (Lee, 2008). Therefore, CPSs must operate in real-time through different forms of control mechanisms, namely open-loop control, feed-forward control, and feed-back control (Gunes et al., 2014). In the work of Shaikh et al. (2014) on the broad literature survey on the multi-objective optimized control for energy and comfort management in buildings were categorized into two: (i) conventional controllers composed of various standard schemes, such as an on/off scheme and proportional integral derivative by considering only energy consumption and (ii) intelligent controllers classified as learning based methods (with AI, fuzzy systems and NN), the Model Predictive Control (MPC) methods and aged based control systems by considering both energy and comfort management (Shaikh et al., 2014). The buildings equipped with sensors and automation infrastructure for the improvement of building energy efficiency were studied by Schmidta and Åhlund (2018) and indicated as a prime example of a closed-loop CPS concentrating on the use of the information for predictive control to be reflected in the future building data. As illustrated the predictive optimization CPS control loop in Figure 2.7, the prediction approaches were categorized broadly into two as being theoretical (based on building physics and other approximations, namely "model-based approach" for predictive control applied in building simulation programs) and data-driven (based on observed data from Building Management System (BMS), linear or non-linear regression models such as NNs are utilized) in the cyber-representation of occupant preferences, a maintenance schedule of building systems, refurbishments, and changes of the weather. An example, in a building scale of CPS, Kleissl and Agarwal (2010) evaluated modern buildings in a large university campus as a cyber-physical energy system and optimized the energy consumption of mechanical systems, lighting systems, and IT equipment according to the information through the sensors which detect the occupant's presence and with the aim of achieving zero net energy buildings (ZNEB), i.e., buildings with zero net annual energy consumption, the alternative for the electricity generation by PVs on the roof was evaluated.

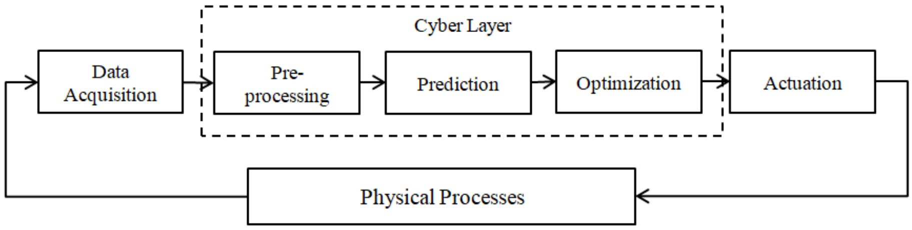

Figure 2.7. Block diagram of the predictive optimization CPS control loop
Source: Schmidta and Åhlund (2018)

The IoT and information system enables the real-time online monitoring and controlling of the IB building systems, and therefore with the collection of real-time data could be used as a basis for future prediction with AI techniques. This enabled the development of robots carrying a variety of tasks by themselves in today's world. As the robots with two different central ideas, situatedness and embodiment, leading the way of behavior-producing modules that removed the need for human intervention, advice, and control (Brooks, 1999). Considering the IB concept, learning and modeling the occupant behavior and preference and acting upon accordingly is of significance. In a recent study of Carlucci et al. (2020), the research efforts until 2020 on the modeling of occupants' presence divided into three sub-domains: occupancy detection, estimation and prediction; activity prediction and room occupation; and people movement between zones were summarized.

Activity recognition and prediction with the learning methods have attracted increasing attention as a research area where AI and Machine Learning (ML) techniques are used since they have proven of learning capability from heterogeneous data set and identify patterns or trends to make accurate predictions for the future system (Manic et al., 2016). The new generation of AI, which is human-like information processing, are achieved with fuzzy logic systems, NNs and generic algorithms, being the methodologies of Computational Intelligence (CI) to solve nonlinear and mathematically non-modeled systems by imitating the nature in problem-solving (Dounis, 2010). Fuzzy logic representations try to capture the humans' way of reasoning with real-world knowledge and artificial neural networks, models of the nervous system, connected with computing elements that have the ability to respond to input stimuli and to learn to adapt to the environment (So and Chan, 1999). Mobile sensing systems are able to get intelligence from gained raw sensed data based on a number of observations to compromise the mathematical model of human activities through data mining and ML techniques (Arsénio et al., 2014) that applies a specific algorithm to a dataset and the algorithm can "learn" from the given data based on the methodology classified into two categories: supervised learning and unsupervised learning techniques **(**Sadeghi et al., 2020). The philosophy behind the ML is to automate the learning process that enables algorithms to create analytical models with the support of available data and it is applied in different learning styles, including supervised learning, unsupervised learning, semi-supervised learning, as well as reinforcement learning (Qolomany et al., 2019). The collected historical data can be used in AI-based methods for the prediction of building future energy use instead of thermodynamic equations used in engineering (Wang and Srinivasan, 2017). The ML in buildings is to move from approximations into quantitatively supported decisions that improve efficiencies, control costs, and spur performance (Karpook, 2017).

The data-driven models for occupancy pattern prediction in buildings were indicated in the work of Penga et al. (2018) and recommendations were provided for visual needs based on the collected historical data with the application of ML techniques in the work of Kar et al. (2019) and energy saving potentials by using occupancy information in the MPC framework in the work of Oldewurtel et al. (2013). With the aim of investigating the effect of user activity on building energy saving, the relevant studies were analyzed and reached a conclusion that occupancy-based control can reduce 40 % of the energy consumed by the HVAC system and lighting system, separately (Nguyen and Aiello, 2013). In an experiment carried out by Guillemin and Morel (2001), an integrated system with heating, shading device and artificial lighting controllers which continuously adapted itself to the environment by considering user availability and outside weather conditions together with the learning ability of user luminance level preferences was tested to optimize both the user comfort and building energy consumption and the results showed 25% total energy saving for the room where the integrated system installed compared to another room conventionally equipped located in the same office building. Another study by De Paola et al. (2019) proposed a fog-based hybrid intelligent system which adjusted the internal environment parameters (temperature, humidity and lighting level) based on the occupant activities such as eating, relaxing and sleeping automatically and the occupant intervention to the system was observed together with the energy savings in a smart home. Further to the previous studies, sensor-based data is utilized for the optimum building energy management by using rule sets (Doukas et al., 2007), for the adjustment of illumination level according to the changing of occupancy and daylight amount (Pandharipande et al., 2014) and for the user behavior prediction to optimize building energy load from heating, cooling and ventilation systems by also maintaining internal comfort conditions at the same level that indicated a saving of 30% (Dong and Andrews, 2009). Sadeghi et al. (2020) tried to predict the heating and cooling load of buildings based on the available data, relative compactness, surface area, wall area, roof area, overall height, building orientation, glazing area, and glazing distribution by using Artificial Neural Networks (ANN) and Deep Neural Networks (DNN) methods and the results revealed that DNN methods provided more accurate results compared to the ones obtained through ANN methods. A recent literature review of the ML applications for the different phases of the building lifecycle was carried out by Hong et al. (2020). They concluded that there exist successful studies on the fault detection and diagnosis of HVAC equipment and systems, load prediction, energy baseline estimate, load shape clustering, occupancy prediction, and learning occupant behaviors and energy use patterns covering the design, construction, operation, and maintenance, control, and retrofit; however, there were no studies for the commissioning stage.

Feedback control and artificial intelligence techniques are identified as two of the enabling disciplines for a new generation of self-adaptive systems with the self-adaptive software *"capable of evaluating and changing its own behavior for better functionality"* (Macías-Escrivá et al., 2013). In the discussion of the AI techniques in a BAS, Dounis (2010) pointed out that the deployment of these techniques resulted in the achievement of goals, which are energy efficiency, comfort, health, and productivity. The intelligence of the elements was defined as the ability of sense for gathering and processing knowledge, autonomous decision making, as well as communication and coordination of activities with others to react in a real environment (Vrba et al., 2014). Similarly, self-adaptation systems are defined as *"able to adjust their behavior in response to their perception of the environment and the system itself"* (Cheng, et al., 2009). The *intelligence* brings the necessity of taking actions using the collected data through WSNs; hence BAS transforms these data into intelligence (Dounis, 2010). In the light of all these developments on data collection and the ability to respond accordingly brings the features of IBs, namely being self-adaptive based on real-time data. This was pointed out by Lilis et al. (2017) that a reliable and robust system to collect, store and pre-process data from various devices is a necessity for the IBs.

2.4 Intelligent Technical Systems

In this section, the characteristics of intelligent systems are explained. In the research of Taymanov and Sapozhnikova (2014), the three features of intelligence for the devices (sensors and MEMS) with AI are summarized: the first one is the ability of its "carrier" to receive and transmit information from the changing environment and to process this information by a given algorithm and turn into a format; the second feature is to vary its characteristics such as the parameters or the operation algorithm on the basis of information obtained from the ‘carrier's sensing organs, i.e., embedded sensors and the third feature is a control capability of the intelligence ‘carrier’ for its own health that means a self-check ability, self-correction, and self-recovery. In the study of Böke (2019), based on a systematic literature review, a general definition of an intelligent technical system could not be found, but rather, important aspects are given as an application of control principles of mechatronic and adaptive systems and computer technology. As previously highlighted, Bien et al. (2002) defined four intelligent attributes of system intelligence as autonomy, controllability for complicated dynamics, human-machine interaction, and bio-inspired behavioural based technology, and among these, especially “autonomy” and “human-machine interaction” were stressed as being the main intelligent machine characteristics. Furthermore, by using these attributes defined by Bien et al. (2002), in the study of Wong et al. (2008) indicated the “system intelligence” of the IBs by firstly identifying the key intelligent indicators such as self-diagnosis, service quality and customer feedback management, etc. and then appraising the system intelligence of eight main building control systems in a typical intelligent building: integrated building management system (IBMS) for overall monitoring and building management function; heating, ventilation and air-conditioning (HVAC) control system for indoor air quality and comfort control; addressable fire detection and alarm system for fire prevention and annunciation; telecom and data system for communication network backbone; security monitoring and access system for surveillance and access control; smart/energy efficient lift system for multi-floors transportation service; digital addressable lighting control (DALI) system for light design and control; and computerized maintenance management system for inventory control and service works. Technical systems integrated with sensory, actuatory, and cognitive functions (Figure 2.8) are called **intelligent technical systems** whose characteristics were defined as adaptive (adapting to its environment autonomously), robust (operating in a dynamic environment flexibly and autonomously even for the unexpected situations), anticipative (anticipating future impacts on the basis of empirical knowledge), user-friendliness (adapting user-specific behavior and interacting with the user sensibly) (Dumitrescu et al., 2012).

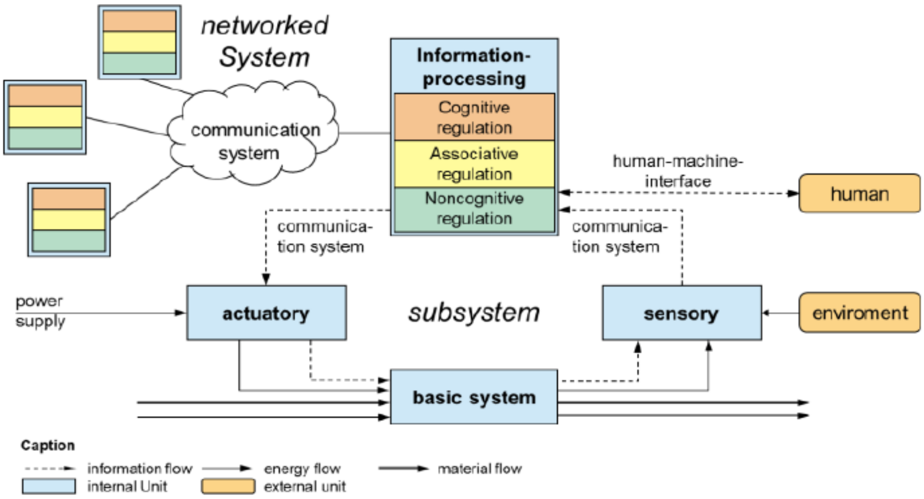

Figure 2.8. Technological concept – from intelligent subsystems to networked, cyber-physical systems

Source: Dumitrescu et al. (2012)

Apart from the intelligent characteristics of systems, other requirements are also influential since IB systems are selected among the innumerable products in the market. To solve this issue, Wong and Li (2009) proposed a framework to determine an IB system based on a disparate selection criterion with different weightings, and as a result, “work efficiency” was appeared to be the core selection criteria followed by “user comfort,” “safety” and “cost-effectiveness.”

Building Management System (BMS), termed also Building Automation System (BAS) and Building Control System (BCS) (Shaikh et al., 2014), is an information management system for the generation of databases and using for decision making by retrieving the data from that databases (So and Chan, 1999); is a programmed, computerized network of electronic devices that are employed for control and monitoring of systems (CABA, 2008); monitors and controls the indoor climatic conditions in building facilities (Shaikh et al., 2014); monitors, supervises, controls and reports on smart building technology systems, such as access control, video surveillance, fire alarms, HVAC control, programmable lighting and electric power management with the four basic functions, providing information on supervised building functions, detection and management of alarm and other conditions, monitoring and reporting of system functions and finally interfacing among smart building applications (Sinopoli, 2010); to control, monitor and optimize building services such as lighting, heating, security, closed-circuit television (CCTV) and alarm systems, access control, audio-visual and entertainment systems, ventilation, filtration and climate control, etc., even time and attendance control and reporting (notably, staff movement and availability) (Nguyen and Aiello, 2013).

Integration of systems *takes place at physical, network, and application levels to share resources* (Sinopoli, 2010) shown in Figure 2.9 and data *processing and its communication (*Arkin and Paciuk, 1997*).*

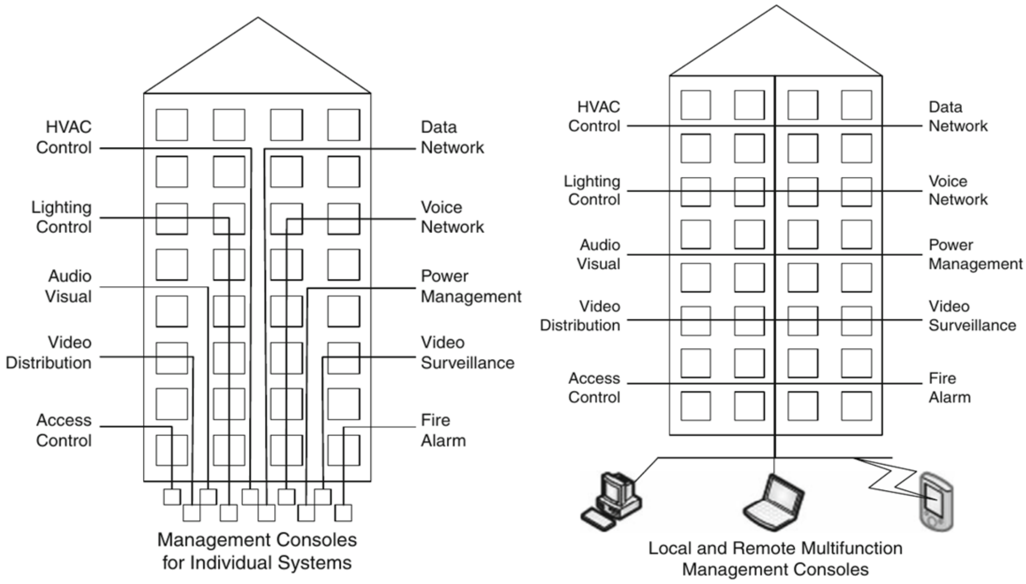

Figure 2.9. Traditional way of design versus integrated building systems

Source: Sinopoli (2010)

System integration is necessary to make the systems work together in an efficient way that results in increased performance and reduced investment and cost for the system (Chung et al., 2001). For the inclusion of BAS functions, upgraded version namely Integrated Building Management System (IBMS), the highest level of integration is called IBMS (Arkin and Paciuk, 1997), integrates all essential building services systems to provide overall strategic management in all aspects, such as analyzing, reporting the building performance and connecting with multiple locations with the aim of automatic control and maintenance of the daily operation (Wong, 2007). IBMS analyses and reports the overall view of building performance by the integration of all building services and the connection of multiple site locations with the aim of strategic management in all aspects. It provides the monitoring and statistical analysis of electricity, gas, water consumption, and automatic control of the normal daily operations as well (Wong et al., 2008). Future integration could be the management of structural elements and smart materials (i.e., smart glazing) by IBMS (Arkin and Paciuk, 1997). The configuration of the system is shown in Figure 2.10, including BAS (HVAC control), fire security system, security and access control, lighting control, and power monitoring by integrating into a single Ethernet backbone (Wang, 2010).

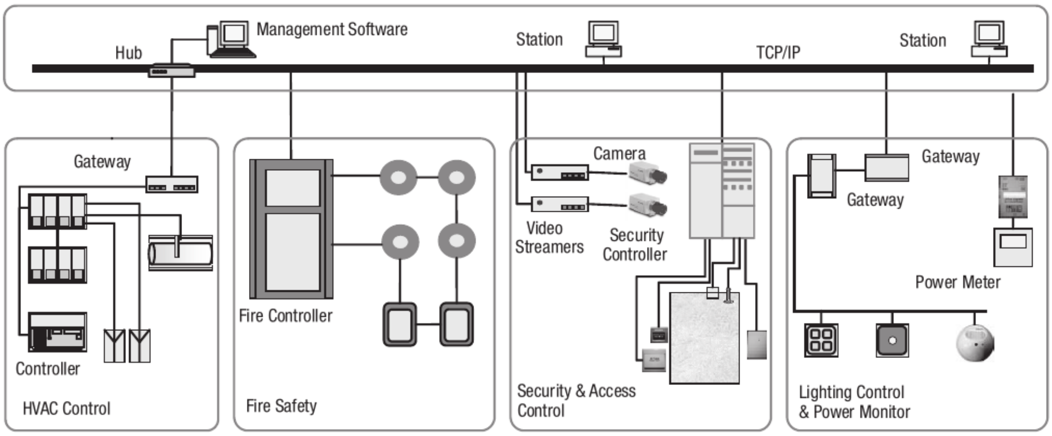

Figure 2.10. An integrated intelligent building system

Source: Wang (2010)

2.5 Intelligent Features of the IBs in the Existing Studies

The second consideration is the several interpretations of the meaning of intelligence in the IB context and specific features of the IBs.

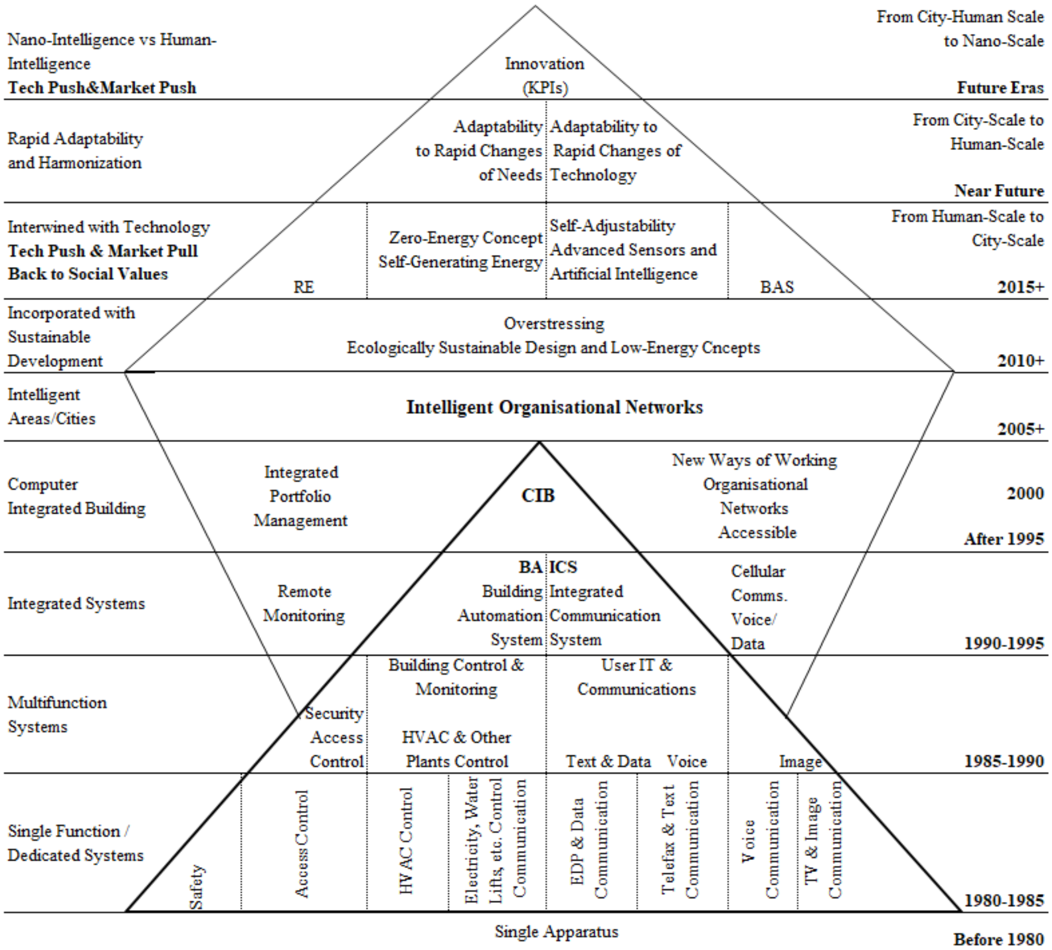

Figure 2.11. Updated IB pyramid (after Harrison, 1999 in Clements-Croomed, 2004, p.26)

Source: Ghaffarianhoseini et al. (2016a)

Ghaffarianhoseini et al. (2016a) analyzed varying IB definitions and key performance indicators (KPIs) in different parts of the world and indicated the general features and characteristics. Ghaffarianhoseini et al. (2016a) suggested overall KPIs as smartness and technology awareness, economy and cost efficiency, personal and social sensitivity, and environmental responsiveness for three key IB components: systems, performances, and services. Figure 2.11 indicates that the movement has started and walked with the technology advancement. The focus has been shifted throughout the years; however, what remains as the basis of the IB concept is energy efficiency and the ability to respond to occupant needs.

In the literature, the essential characteristics of the IB were emphasized in terms of technology and architecture. In terms of technology, Arkin and Paciuk (1997) claimed that fully integrated building control and management and level of integration are vital for the IB. Yang and Peng (2001) stated that the major asset of an IB lies within its ability to learn and adapt. CABA (2008) pointed out timely, integrated system information for making intelligent decisions regarding its operation and maintenance. In the interview conducted by Zağpus (2002), one of the professionals summarized the intelligence criteria in three main parts: all electronic devices should be very intelligent, all equipment should be wirelessly connected to a network, there has to be a high-speed network so that all devices could be connected via socket or wireless. Himanen (2003) defined a number of features implemented in the IBs throughout a survey as “end-user need orientation, system integration, spatial flexibility, movable space elements and equipment, comfort (indoor air quality), concentration on work (work satisfaction), working efficiency (flexi-work), the image of the building (values and types of buildings), space selection criteria, information intensity (control and regulation of HVAC, office automation, paperless office), interaction (among occupant companies, communication, awareness of the use of ICT, participation in design), service-orientation (building amenities, user interface), ability to promote health (health symptoms), adaptability.” According to Clements-Croome (2004), the IBs should be sustainable, healthy, technologically aware, meet the needs of occupants and businesses, and should be flexible and adaptable to deal with change. Likewise, CABA (2008) defined key intelligence attributes are sustainability, reliability, mobility, efficiency, interoperability, security, technology, flexibility, scalability, longevity.

Furthermore, the architectural characteristics were described by various researchers. Chwieduk (2003) expressed energy-efficient buildings (the IBs) as bioclimatic building design and orientation, integration of solar power generation systems, energy storage, heat pumps, heat recovery, waste sorting, and water management. Rational energy use, minimum operational cost, and enhanced safety and comfort to users were given by Silva et al. (2012) as the characteristics of IBs. In the review of smart house case models, GhaffarianHoseini et al. (2013) emphasized that the 'enhancement of the quality of life', 'improvement of comfort' and 'enhancement of safety and security' are the main design objectives of smart houses intertwined with sustainable features for energy saving. The environment of the IBs described by Clements-Croome (2011) as having a fresh thermal environment, fresh air, good natural lighting, minimum glare, adjustable settings for different types of working, ergonomic workplaces, and minimum pollution. To et al. (2018) collected responses on the features of smart and sustainable buildings from 543 Hong Kong's building professionals and the results revealed that intelligent security, intelligent and responsive fresh air supply, and intelligent and responsive thermal control are among the most important ones.

In the studies that emphasize responsiveness (Clements-Croome, 1997; Clements-Croome 2004; Clements-Croome, 2011; Chen, 2013; GhaffarianHoseini et al., 2013; Kroner, 1997; Powell, 1990; Wiggonton and Harris, 2002; CABA, 2008) mainly responding to the changes occurring in the environment is one of the main IB characteristics. Given the name of highly responsive buildings was defined as "*substantive potentials of automatic control and monitoring towards optimizing ambient intelligent environments while balancing this approach with the human values, well-being, health, and quality of life*" by Ghaffarianhoseini et al. (2016a). Intelligent buildings adapt to external (seasonal) and internal (occupancy and usage patterns) changes with the aim of increased autonomy and sustainability (Manic et al., 2016). Clements-Croome (1997) answered the question of 'what do we mean by intelligent buildings?' and expressed the fundamental meaning of the term IBs as it copes with social and technological change and is adaptable to short-term and human needs, and that could be achieved by studying the inter-relationships between work patterns, environmental systems, and building forms. An implicit logic that evolves with changing user requirements and technology is a necessity for the IBs to ensure continued and improved intelligent operation, maintenance, and optimization (CABA, 2008).

Having considered the information above, the literature review raises the question of which features make a building 'intelligent'?

2.6 Performance Evaluation Methods of Intelligent Buildings

Apart from the definition and characteristics of the IBs in literature, many researchers have evaluated the benefits or performance of the IBs by developing tools. The total building performance was evaluated in terms of user satisfaction, organizational flexibility, technological adaptability, environmental and energy effectiveness (Hartkopf and Loftness, 1999). Intelligent architecture can be measured by how well it supports the management of intellectual capital, which is the intangible assets of skills, knowledge, and information (Kroner,1997).

Over the last 20 years, a variety of assessment tools have been developed in different parts of the world and have become very popular due to the significant increase in the number of certified buildings. The government institutions have also created intelligence assessment tools for the measurement of building intelligence as well as academic works (Chen et al., 2006). Green certification systems are the most favorable ones for the assessment of sustainability, namely Building Research Establishment Environmental Assessment Method (BREEAM) in UK, Leadership in Energy and Environmental Design (LEED) in USA; Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan; the international collaboration framework, Green Building (GBTool) and then named as Sustainable Building (SBTool). For instance, the GBC'98 assessment framework, the result of two year GBC challenge and adaptable to regional circumstances, has six performance categories, namely as resource consumption (energy, land, water and materials), environmental loadings (airborne emissions, solid waste, liquid waste and other waste), indoor environment (air quality, thermal quality, visual quality, acoustic quality, controllability of systems), longevity (adaptability, maintenance of performance), process (design and construction process, building operations planning) and contextual factors (location and transportation, loadings on immediate surroundings) (Cole and Larsson, 1999). The previous research on the measurement of intelligence can be classified in terms of (i) system intelligence (Huang, 2014), (ii) system integration (Arkin and Paciuk, 1997; Yang and Peng, 2001), (iii) use of one or more combinations of performance indicators in social, environmental, technological and economic aspects, also concentrated on reducing in use of energy and resources (Chen, 2010; Arditi et al., 2015; So et al., 1997; ALwaer and Clements-Croome, 2010; Chen et al., 2006; Kaya and Kahraman, 2011; Moghaddam, 2012; Fathian and Akhavan, 2006), (iv) enhanced occupant productivity (Bordass and Leaman, 1997; Preiser and Schramm, 2002). The details of those studies are summarized in the following paragraphs. It is noteworthy that the same performance indicators are used for both sustainable buildings and intelligent buildings, and therefore, sustainability is one of the essential aspects of building intelligence.

So et al. (1997) defined eight quality environment modules as (1) environmental friendly - health and energy conservation (M1); (2) space utilization and flexibility (M2); (3) life cycle costing - operation and maintenance (M3); (4) human comfort (M4); (5) working efficiency (M5); (6) safety - fire, earthquake, disaster, and structure, etc. (M6); (7) culture (M7); (8) image of high technology (M8) where each of the key modules will be assigned a number of facilities in the order of priority. In a similar approach, Asian Institute of Intelligent Buildings (AIIB) developed an Intelligent Building Index (IBI); where ten main categories composed of 378 elements are green, space, comfort, working efficiency, culture, high-tech image, safety & structure, management practice & security, cost-effectiveness and health & sanitation (Chow and Leung, 2005; So and Wong, 2002). Fathian and Akhavan (2006) evaluated the intelligence level in the buildings in terms of eight areas: architecture which is the foundation of the model, service and support systems, security, communication systems, safety, system management, comfort. A web-based building intelligence quotient programme which rates BAS in existing large office buildings developed for the Continental Automated Buildings Association (CABA) in order to support the integrated design and life-cycle costing processes and contribute convergence of green and intelligent building programmes (Katz and Skopek, 2009). The facilities intelligence was evaluated in STEEP (social, technical, economic, environmental, and political) criteria in which (i) social criteria covered public satisfaction, cultural compatibility, community acceptability, and workforce availability; (ii) technical criteria covered preparedness to site conditions change, integration of multiple functionalities with ICT systems, easiness in facilities management, easiness and security inaccessibility, and evacuation; (iii) economic criteria included preparedness to demand and supply changes, possibility to maximize lifecycle value and accessibility in the local area; (iv) environmental criteria covered degree of eliminating environment impacts, preparedness to climate change and finally political criteria represented fitness to management specifications (Chen, 2010). Arditi et al. (2015) developed a smartness index for the evaluation of buildings where facility managers rated 16 variables in three domains, economic performance, energy performance, and occupant comfort performance via a Likert scale scoring system.

Some of the studies created a new assessment method by using the existing indicators or criteria from a number of relevant prevailing studies. The study by ALwaer and Clements-Croome (2010) derived key performance indicators (KPIs) related to sustainable intelligent buildings from the existing tools such as LEED, IBI, BREEAM, and HK-BEAM. These indicators were classified under four groups as environmental indicators group (energy and natural resources, materials used, durability and waste), socio-cultural indicators group (functionality, usability, and aesthetic aspect, indoor environmental quality, health and well-being, innovation and design process), economic indicators group (flexibility & adaptability, economic performance, and affordability) and technological indicators group (intelligence and controllability). In a similar vein, the study by Moghaddam (2012) constructed an assessment model from AIIB index and previous studies and then created a new assessment scheme which included six main intelligent building systems, HVAC, BAS, fire alarm, security, vertical transportation, and lighting systems. By using the previously defined criteria in the literature, Kaya and Kahraman (2011) proposed a fuzzy multiple attribute utility model for an intelligent building assessment and indicated the evaluation of three intelligent office buildings in İstanbul. Chen et al. (2006) developed a multicriteria decision-making model using the Analytic Network Process (ANP) called IBAssessor by selecting 43 indicators from AIIB methods having 378 indicators based on their energy-time consumption index. This enabled an evaluation of the building in terms of its energy efficiency performance during its lifespan.

With the aim of measuring occupant satisfaction, the Post Occupancy Evaluation Method (PoE) covers energy and technical performance, the efficiency of space utilization, occupant comfort and productivity, management, environmental impact, and cost-in-use (Bordass and Leaman, 1997). It facilitates obtaining feedback related to the real performance of buildings in the context of a given location, culture, and building users during the different phases of the building as its three stages explained in the study of Preiser and Schramm (2002).

On the other hand, some assessment tools evaluated the intelligence from the perspective of system intelligence. For instance, Huang (2014) categorized intelligence indicators into three as technology (24 indicators), function (18 indicators), and economy (5 indicators) for evaluation of intelligent residential communities in China. Moreover, one of the venues for achieving the goals of creation of personal, environmental, and technological conditions for the occupants is integration (sharing of information) among the buildings' service systems (Arkin and Paciuk, 1997). In this regard, quantification of system integration was studied by Arkin and Paciuk (1997), namely the magnitude of systems' integration (MSIR Index) was developed in order to compare various building intelligence (Table 2.4). Further, MSIR Index was adapted with the incorporation of the LCC method by Yang and Peng (2001).

Table 2.4. Scale for systems' integration in intelligent buildings

Source: Arkin and Paciuk (1997)

Level	Type of integration	Attributes and description	Rating
5	No integration		1
4	One directional	No feedback; safety codes	2
3	Interfacing discrete systems (one to one)	Advanced smoke control; PBX; LAN	3
		Other; modern	4
		Sophisticated controls; integration with a smart structural element	5
2	BAS; EMS; CMS; OA	OA*; STS*	6
		BAS; EMS*; CMS*; etc.	7
		As above + maintenance and billing; integrates smart structural elements; personal environment	8
1	IBMS	Partial IBMS	9
		Full IBMS, includes maintenance and billing and smart structural elements	10

*CMS (Communication Management System); OA (Office Automation); STS (Shared Tenant Services); EMS (Energy Management System)

The Building Rating Method (BRM) has retained the normative weighting approach used in the 1992 IBE method covering building site/location, building shell/skin, organizational and work process issues, and building services/technology (Harrison et al., 2012). Cho and Fellows (2000) gave some examples of what the IB means for office buildings in practice by evaluating six high rise buildings in Hong Kong in terms of incorporated intelligent building design features (structure, systems, and IT provision), the importance of the features to the users' requirements and performance of the features from occupants' perspective. Their results have been evaluated according to the BRM method and indicated that the majority of the buildings marketed as intelligent are underachieving intelligence (Figure 2.12).

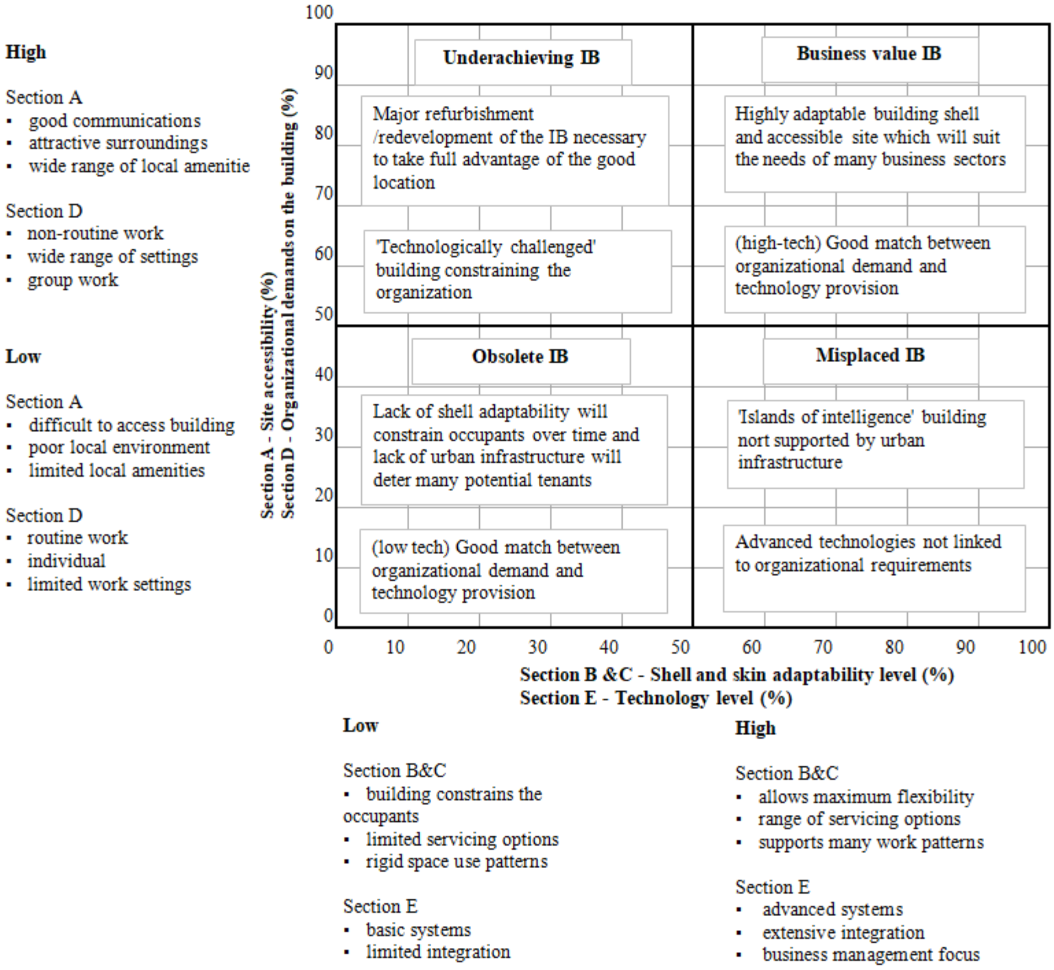

Figure 2.12. BRM Method scoring matrix

Source: Harrison et al. (2012)

2.7 Current Gap in the Literature

The existing definitions of the IB revealed that how its definition has evolved throughout time. In the early ’80s, a building in which information technology was incorporated and the buildings with automated functions were called IB. In the 1990s, occupant satisfaction in terms of meeting their requirements became the new focus. This was followed by the installation of BMS with a passive design approach between 2000 and 2010. After 2010, its meaning was extended to the inclusion of sustainability and energy efficiency. In the 2020s, communication with the occupants and learning ability are integrated into the IB concept with technological advancements. One common point revealed from those definitions is that the reason/idea behind the implementation of intelligence in buildings is mostly to enhance the occupant's well-being.

The varying definitions of the IB in the literature covering very different and broad aspects have resulted in losing its focus and meaning; hence, its use in the built environment became confusing. The previous researchers put this forward in the course of time: little consensus on what makes a building intelligent or how it assists the users of buildings (Harrison, 1992); the official definition of the IB has not yet been standardized around the world (So et al., 1999); the definitions are very subjective in nature (So and Wong 2002); the definition of typical, good and excellent practice in intelligent buildings does not exist (ALwaer and Clements-Croome, 2010); there is no single definition accepted worldwide (Wang, 2010). Based on findings of the study on the analysis of IBs definitions in different contexts/countries, Ghaffarianhoseini et al. (2016a) pointed out that there is no standard definition for IBs, rather diversified interpretations and inferences exist in this field.

In 2005, the literature review revealed a lack of information and support for decision-making of intelligent building investment during the conceptual stage (Wong et al., 2005). Assessment of building intelligence is under study due to the various definitions and interpretations of the IB. A gap is a comprehensive tool for other IB features, such as performance, technology, architecture, and functionality, etc., is necessary (Arkin and Paciuk, 1997). Most of the assessment methods are inapplicable in practice due to their conceptual complexity and have a personal bias arising from the assignment of weights by an expert (Huang, 2014). Furthermore, in the literature, there are approaches for intelligence assessment for buildings mostly derived from the existing tools such as AIIB Index, LEED. The performance indicators taken from these tools are easy to understand by the evaluators due to their common usage. Similar to the IB definitions, these approaches evaluated intelligence in the context of different perspectives, such as sustainability, adaptability, level of technology, or occupant satisfaction. For example, the ones derived from LEED and BREEAM are evaluated through the sustainability aspect. AIIB Index has 378 elements to be considered for the evaluation, which makes its content quite broad. This was also highlighted by Arditi et al. (2015) that the measurement of the smartness of a building is complicated because there are many issues to be considered, and perceptions do differ based on the role of the project participant. Chen (2010) evaluated facilities intelligence, and Bordass and Leaman (1997) assessed the buildings only by measuring the occupant satisfaction meaning that occupants' view is vital to understand the building performance. Lastly, the BRM method has an extensive framework covering the meaning of intelligence; however, the method concentrated on the adaptability aspect together with the level of match between organizational demand and technology provision.

In the light of the literature review results, the IB definitions provided by previous researchers have not provided a direction of focus towards building intelligence. This has caused the loss of the main goal and core idea of the IB concept. According to Harrison et al. (2012), the measurement of intelligence depends on how intelligence is defined. Thus, likewise the definitions in the literature, the existing intelligence assessment tools cover either too many aspects or only one aspect of the intelligence. In conclusion, looking through the evolution of its definition, it is apparent that it is not possible to give one definition which lasts throughout time. It will continue its evolution in the future with the inclusion of new features especially due to the advancements in technology. Therefore, the current gap is to find out a common understanding of the IB concept agreed on an international level by considering the current expectations, interests, and technology in today's world. In addition to this, another gap is the absence of a guidance to follow for the achievement of building intelligence during the predesign phase. Therefore, an intelligence measurement framework developed from the IB definition is necessary.

CHAPTER 3

AN EXPLORATORY STUDY TO IDENTIFY FEATURES OF IBs: THE SURVEY

This chapter explains how the survey was developed in order to find the response to the research questions. A phenomenology method, a qualitative way of conducting research, was used. It is defined by Trochim and Donnelly (2001) that it is a philosophical perspective as well as an approach to a qualitative methodology that focuses on people's subjective experiences and interpretations of the world. Thus, the survey was the best among alternatives as a research method for collecting current ideas, perceptions, experiences, and life lessons of professionals since exploratory research was necessary for the area of IBs. Thus, a survey was designed for a focus group to figure out the meaning of intelligence considered. After approval of the survey with the focus group, it was sent to experts in the built environment to collect their perceptions.

3.1 Survey Design

The IB concept is a phenomenon having multiple aspects. For the composition of the survey, the IB features were selected from the previous studies with the conceptual construct approach. The conceptual constructs are used to model the unstructured phenomena to measure "unquantifiable" dimensions and variables. Furthermore, it helps the researchers capture the critical aspects of a phenomenon with the aim of decomposing a phenomenon into specific aspects, 'building intelligence' in this particular case. As schematized in Figure 3.1, descending the abstraction ladder from general to the particular, the phenomenon is divided into specific facets; *conceptual constructs* describe a limited number of its aspects, then only critical aspects of the construct have been selected as *dimensions* and finally variables, indicators, and measures are composed (Geisler, 2000).

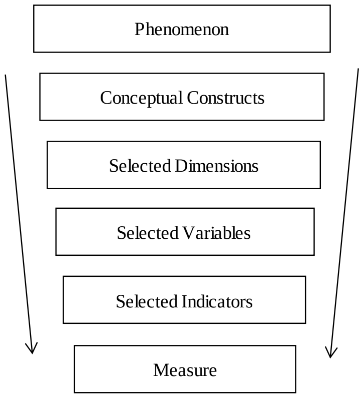

Figure 3.1. The abstraction ladder in capturing critical aspects of complex phenomena
Source: Geisler (2000)

Following the abstraction ladder in Figure 3.1, the questionnaire survey represents the "conceptual construct" and the "indicators," expressed as features in the survey, raising concerns on critical aspects of the phenomenon, the IBs. Each feature, explained in the following paragraphs, addresses another aspect of the intelligence of buildings; however, there are still overlapping and overlaying among the features due to the existence of a broader way of interpretation and understanding.

The questionnaire consisted of three parts designed to gather information on (1) experts' demographic information, (2) definition and features of intelligent buildings, and (3) experts' perception on the importance of IBs' features. It aimed to understand the building intelligence only from the perceptions of experts in the built environment; hence, no information related to the intelligent building literature was provided in the first and second parts, assuming that their way of understanding might be affected.

Part 1 contained questions regarding the demographics of the experts. In Part 2, two open-ended questions on the definition of IBs were asked to collect the ideas of the professionals since the use of a structured survey limits the responses of the participants, with also giving an example of intelligent building in the real world. In part 3, the survey participants were asked to rate the importance of intelligent building features on a five-point Likert scale. Three clusters for the assessment of intelligent building features were used in this research: (i) Building Management System (BMS) related to management and controllability of the IBs; (ii) Advanced Technology (ADV) related to the implementation of technology and (iii) Design Management (DM) related with the design considerations. The point of this grouping is to express a wide variety of concepts and information in the literature sources by using an affinity diagram. Regarding the features given in the survey, the main focus was on the collection of different project stakeholders' views rather than technical and theoretical discussion regarding the design concepts. Therefore, technical terms are kept simple for the expression of the features so that the respondents would not be overwhelmed with a load of information. Moreover, at the end of each attribute of IB, a blank space was left to allow the respondents to express their opinion or provide additional ideas/information, and this increased the possibility of adding a new feature or eliminating the inapplicable one. The detailed version of the survey is given in Appendix A.

3.2 Focus Group

With the intention of checking the clarity of the questionnaire survey in terms of wording, readability levels, type of question, and its format and gaining feedback both on the features of IBs extracted from the previous studies and the validity of the questionnaire survey content, a focus group was composed of seven industry experts, four architects and three mechanical engineers who work in the area of building design development.

3.3 Data Gathering

Purposive sampling, a feature of qualitative research (Cohen et al., 2011), has been used in this study. An online survey was preferred to reach out to the building sector representatives who have in-depth knowledge of the IBs and relevant experience. Thus, the survey link was sent to the groups of design-led professionals, the researchers, and also expert companies working on the exemplary buildings and in the area of intelligent buildings all over the world, which enabled the involvement of a wider range of participants and the collection of less subjective results. In order to reach the experts more easily, the respondents were contacted at their business e-mail addresses collected from the official websites of the companies. Further, the distribution of the survey to the design professionals from different countries within the diversity of global cultures and climatic contexts was the first priority. The survey was conducted during the spring and summer months of 2020 by sending the survey attendance link to experts in the built environment.

3.3.1 Intelligent Features of Office Buildings

In this part of the survey, intelligence in buildings was measured by a Likert scale created conceptually based on a set of different features analyzed in the literature as well as a number of projects that were portrayed as *intelligent.* The features are questioned for their degree of importance to the building intelligence in the survey.

Measurement means the assignment of numerals to objects/events based on the rules and scales is possible if there is a certain isomorphism between the aspects of objects and the properties of the numeral series (Stevens, 1946). The basic idea behind this method is the measurement of a phenomenon with the aggregating an individual's ratings according to their feelings, knowledge on a series of items and statements (Harpe, 2015). Throughout this view, the Likert scale method was used as a measurement tool of this thesis to collect the experts' opinion on a set of features' importance level of IBs which were organized into three main categories, namely, Building Management System (BMS), Advanced Technology (ADV) and Design Management (DM) where each aspect focus on certain areas of the IB design.

Many statistical procedures have been developed to evaluate the data derived from the Likert scale (DeVellis, 2003). There exists a great discussion in the literature on how the collected data should be used in the statistical analysis, and still no straightforward method exists, i.e., three main decisions should be made before going into statistical data analysis; type of data, use of summated scale results and decision for the statistical analysis method. Firstly, the type of collected data is arguably discussed whether it is accepted as interval or ordinal scale based on Stevens' measurement framework that defined four types of scale as nominal, ordinal, interval, and ratio (Stevens, 1946). In some studies, the removal of the neutral category, which forces the respondents to make a decision, was questioned since using a midpoint affects the data in terms of validity and reliability (Bartram, 2007; Chyung et al., 2017; Cohen et al., 2011and Croasmun and Ostrom, 2011). On the contrary, in the original Likert's article, five options were used with a neutral option, and the distances between the anchors (e.g., "Strongly Agree" to "Agree") are set as equal. Another study conducted by Nadler et al. (2015) found out that participants tend to select the midpoint more than the "no opinion" option; however, use of the 4-point scale with "no opinion" has resulted in higher means compared to the 5-point scale. Moreover, Chyung et al. (2017) summarized the existing studies in this area, indicating that 4-point-scale are accepted as ordinal scales whereas 5-point scales are treated as interval scales and suggested using a 5-point scale. This is also supported by Harpe (2015) that the individual rating item having a response format of at least five categories may be treated as continuous data. Therefore, the presence of mid-point affects the type of data and the decision of appropriate descriptive statistics (e.g., medians for ordinal data, arithmetic means for interval data) and also inferential statistical analyses (parametric statistical tests and nonparametric approaches), which are explained in the following paragraph. Under the guidance of these studies, in the survey, a numerical rating scale is not used; verbal expressions (anchors) were given for each numerical option in terms of both their direction (very important, not important) and intensity (strongly or not), which represents levels of importance since the verbal label for each point is more reliable according to Schwartz et al. (1991). Moreover, five point-scale was used with the fully anchored points as "Very important," "Essentially Important," "Neutral," "Weakly important," "Not important" (illustrated in Figure 3.2). For each item, the response options were considered equally spaced numbers accompanied by equally distanced expressions similar to the study of Likert (1932). Hence, the requirements of a Likert scale also defined by Uebersax (2006) were met, and despite many different views for the type of data, the derived data was evaluated as "interval" according to Steven's classification in this thesis.

Application of natural/passive design strategies instead of active systems

Not important	Weakly important	Neutral	Very important	Essentially Important
[ ]	[ ]	[ ]	[ ]	[ ]

Figure 3.2. An example for a Likert item in the design management likert scale

Another important issue is that the difference between a Likert scale composed of multiple items, also referred to as "summated or aggregated scale" and a Likert item composed of a single item referred to as "Likert-type item," as explained in the articles (Uebersax, 2006; Brown, 2011; Joshi et al., 2015; Clason and Dormody, 1994). In the original Likert scale (Likert, 1932), instead of analyzing the individual items, the individual items were combined via summation or taking the arithmetic mean. Since the overall phenomenon is measured with a group of multiple items, then aggregated score must be used for the statistical analysis (Harpe, 2015; Joshi, 2015). This important difference between the item and the aggregate scale enables selecting the type of statistical analysis approach as studied in the literature. According to Brown (2011) and Boone and Boone (2012), the likert-type item is accepted as ordinal data, while likert (summated) scale could form an interval scale. Harpe (2015) supported that aggregated rating scales can be treated as continuous data. In this regard, descriptive statistics and parametric statistical tests (e.g., t-test) could be used for likert (aggregated) scale (Boone and Boone, 2012; Brown 2011; Carifio and Perla, 2008; Harpe, 2015; Likert, 1932; Joshi, 2015). On the other hand, the article review of Clason and Dormody (1994) indicated that 54% of articles reported descriptive statistics, and 34 % of the articles used parametric tests for likert-type data. Further, the use of parametric tests depends on three conditions for the research sample data, i.e., independency, normality, and homoscedasticity (Sheskin, 2000; McCrum-Gardner, 2007); otherwise, non-parametric methods, i.e., Mann Whitney-U test could be performed. However, Norman (2010) proved that parametric statistical tests could also be used for the evaluation of likert data, even for non-normal distributions. Moreover, it was stated in the article of Likert (1932) that the likert scale data resembles a normal distribution. It is also important to point out that parametric statistics are more powerful and sensitive (Carifio and Perla, 2008) and more robust (Harpe, 2015) than non-parametric statistics.

After short literature research, it was noteworthy that the likert-type item was analyzed individually rather than a likert (summated) scale and presented with descriptive statistics in most of the studies. Further, in those studies, some of them (Bulut et al., 2015; Bulut et al., 2016; Vassileva, 2012; Pan and Pan, 2018; Davis, 1999) preferred to use the parametric statistical test (i.e., ANOVA) for the likert-type item data without consideration of normality of the data while other studies (Amasyali and Gohary, 2016; Azizi et al., 2019) performed non-parametrical statistical methods (i.e., Mann-Whitney U and Kruskal-Wallis H) to compare the perspectives between the groups of respondents. On the contrary, Francom (2020) combined the individual (likert-type) items into likert (summated) scale in order to use for ANOVA and t-test statistical methods.

In summary, despite all controversy evaluations and suggestions in the statistical community above, because five responses were offered for each feature, the likert type-item data was accepted as interval (continuous) data in this thesis. Hence, statistical results of this survey are presented at the likert-type item level with descriptive statistics in terms of means and standard deviations and the percentages of each category as well.

3.3.1.1 Building Management System (BMS)

There were three concerns in the literature related to the controllability of systems (i.e., how much control shall be given to the occupant; the systems shall run in accordance with the defined program or being adaptive to the changing conditions each time by responding) and how the data (occupancy, outdoor environment, occupant behavior or preferences) collected from the building environment.

Table 3.1 lists the features collected from the literature related to the management of building systems and façade elements which may be either automated (programmed) or self-adaptive based on the external climate conditions, i.e. time of the day, amount and angle of sunlight and occupants' behavior patterns according to their preferences. IBs, while providing an automated or self-adjusting environment, should also let occupants live their lives individually; the necessity of data collection for optimization of systems and real-time reaction could be accomplished by observing the occupant with sensors or collecting the subjective occupant feedback throughout a mobile application or a post-occupancy satisfaction survey.

Table 3.1. The referenced articles for each feature for BMS

	Features included in the survey	References
BMS1	Occupant feedback about building in terms of comfort and satisfaction	Brwon et al., 2009 D'Oca et al., 2018
BMS2	Lighting System (Self-adaptive control based on real-time indoor/outdoor environmental data (daylight intensity and occupant behavior pattern/feedback))	Wong and Li, 2009 Manic et al., 2016 Schmidta and Åhlund, 2018
BMS3	HVAC System (Self-adaptive control based on real-time indoor/outdoor environmental data (weather and occupant behavior pattern/feedback))	Wigginton and Harris, 2002 Wong et al., 2008
BMS4	Degree of control by the occupants for radiant temperature and fresh air/odor environmental personal control capability	Fathian and Akhavan, 2006 Brwon et al., 2009

Table 3.1. The referenced articles for each feature for BMS (cont'd)

	Features included in the survey	References
BMS5	Degree of control by the occupants for the levels of artificial lighting, daylight shading, and glare	Brwon et al., 2009 Clements-Croome, 2011
BMS6	Façade System (Self-adjusting façade elements based on real-time environmental data (weather and occupant behavior pattern/feedback) with learning ability)	Kroner, 1997 Wyckmans, 2005 To et al., 2018 Schmidta and Åhlund, 2018 Böke et al., 2019
BMS7	Manual control of façade elements for daylight, solar gain, and ventilation	Wigginton and Harris, 2002 Wyckmans, 2005
BMS8	Façade System (Pre-programmed active control of façade elements in BMS for daylight, solar gain, and ventilation)	Wigginton and Harris, 2002 Wyckmans, 2005
BMS9	HVAC System (Pre-programmed zoning control in Building Management System)	Kroner, 1997 Wong et al., 2008
BMS10	Lighting System (Pre-scheduled zoning control in Building Management System)	Wong et al., 2008
BMS11	Real-time surveillance of occupant behavior for data collection	GhaffarianHoseini et al., 2013 Nguyen and Aiello, 2013 Ghayvat et al., 2015 To et al., 2018

Ultimately, in the questionnaire survey, two options for the way of control of HVAC, lighting and façade elements, namely pre-programmed (automation with weather data or on/off scheduling) and self- adaptive control (natural intelligence model predictive/fuzzy learning ability), were asked to find out which alternative is perceived as more *intelligent*. Furthermore, the method for surveillance where the data is collected was questioned whether being the real-time observation of occupant behavior and preferences or collection of occupant feedback, meaning that the occupant shall understand the operations of the building and provide the subjective feedback accordingly as interoperability and communication which is not only between the systems and the building but also between the occupant and the building is important. Another important feature is the individual and personal comfort control of the inhabited environment by occupants since the occupant behavior has a huge impact on the overall building management and the consequent building energy management and consumption. This feature also has a direct relationship with occupant satisfaction resulting in improved productivity and health and well-being.

3.3.1.2 Advanced Technology (ADV)

Since the wide range and variations of advanced technologies employed at present and the system engineering become important since the *intelligence* of building systems, essentially for safety, security, and vertical transportation systems is measured based on how much is done beyond the requirements of existing regulations and standards and the level of system integration such as the intelligence measurement tool, MSIR index. Therefore, in the survey and this thesis, the wording of "advanced" has been used to express the sophistication degree of systems with AI techniques to go further than the requirements of building standards and regulations (Table 3.2). For example, an advanced vertical transportation system has the ability to predict the amount of traffic and make the necessary adjustment in its speed and program during the day and advanced safety and security systems could be AI-based security systems or use of robots. Moreover, the point is that the learning ability with machine learning algorithms, including the rule-based expert systems (e.g. ANN or fuzzy logic algorithms) is being studied in the research world. Especially, the current aim is mapping the user behavior and use for the decision process in buildings. As a matter of fact, very little information exists on the behavior of the building in relation to the learning ability; rather, the control strategies were studied, generally described as automated. Therefore, the ability to learn and adjust its performance, embedded sensors, cyber-physical systems are being used in many applications from smart vehicles, transportation systems; hence, the effect of IoT and AI was questioned on the *intelligence* in buildings in the survey.

The availability of high-speed communication lines in the city affects the building systems to connect with the city services and the overall speed of communication within the building. Therefore, the type of communication lines, their connection with smart cities such as fiber-optic networks, and the smart grid are asked to the experts as no future smart cities can be imagined without IBs (Lilis et al., 2017). Furthermore, a standard structured wiring solution can significantly increase the lifespan of cabling infrastructure in a building, obviating extensive changes or expensive upgrades (CABA, 2008). On the other hand, advanced network technologies brought the wireless technology, namely, IoT, which led to more efficient and easy way of communication and remote controllability of systems from a central location. Thus, the comparison of physical cabling infrastructure and wireless technology was asked to experts in order to evaluate the use of recent Information and Communication Technologies (ICT) in buildings.

Table 3.2. The referenced articles for each feature for ADV

	Features included in the survey	**References**
ADV1	Availability wireless communication network	Hartkopf and Loftness, 1999 Wang, 2010
ADV2	Connection to smart built environment	Gunes et al., 2014 Lilis et al., 2017
ADV3	Easy access to fiber-optic network	So et al., 1999
ADV4	Advanced fire detection and protection system	Wong et al., 2008
ADV5	Level of integration	Arkin and Paciuk, 1997 Himanen, 2003 Sinopoli, 2010 Clements-Croome, 2011 Chung et al., 2001
ADV6	Automatic fault detection ability	Silva et al., 2012

Table 3.2. The referenced articles for each feature for ADV (cont'd)

	Features included in the survey	References
ADV7	Smarter cleaning and maintenance of the building	So et al., 1999 Wong et al., 2008
ADV8	Advanced security monitoring and access control system	Fathian and Akhavan, 2006 Wong et al.,2008 To et al., 2018
ADV9	Remote control ability	Wong et al., 2008 CABA, 2008 Ghayvat et al., 2015
ADV10	Installation of a structured wiring infrastructure network	CABA, 2008
ADV11	Advanced vertical transportation system	Wong et al., 2008
ADV12	Self-learning ability for the prediction of future uncertainties	Clements-Croome, 1997 Sharples et al., 1999 Wigginton and Harris , 2002 Ghayvat et al., 2015 Schmidta and Åhlund, 2018 Mofidi and Akbari, 2020

3.3.1.3 Design Management (DM)

The core ideas considered in the area of design quality are shaped based on the cost performance in general because they are quantifiable. However, a wider perspective should be drawn by considering other benefits, including human comfort and health, safety, environment with incorporating sustainability in the setting of project goals.

The improvement of the physical performance of buildings reduces the HVAC loads, therefore the requirement to import energy from non-renewable sources; that can be achieved with the building structure (e.g., orientation) to get benefit from the passive solar potential in terms of heating and daylight and natural ventilation; envelope quality – insulation and thermal mass, also increasing the user satisfaction level and improve the energy efficiency during its operation. As a result of preliminary study, the reduction of energy load and applying natural strategies for minimum energy use are questions in this survey. It should be noted that the proposed strategies are expressed as “natural,” which supports the use of passive approaches rather than the use of intelligent techniques or strategies since “natural” represents the high levels of “intelligence.” After the integration of the IBs with the surrounding ecological systems based on the decisions made based on micro-climate conditions during the design phase, renewable energy technology is used for the generation of its energy at the site. Improvement of adaptability is another critical concern of building design since both the longevity and any potential consequence related with technology obsolescence affect the usability and economic value of the building. In time, the changes might be in size or function, capacity, and obsolescence of systems (or even the technology). In line with this consideration, flexibility in structure (i.e., easy modification of the wall), service elements for the possible future changes, easy upgrade of the systems are vital, and so asked the experts.

During the design phase, involving building users in the decision-making helps define the requirements more clearly. Moreover, the building occupant should be explicitly informed how the building systems works and based on which scenarios, building energy management strategies are created so that they will be able to behave accordingly and the inappropriate human action will be prevented in case of any inefficient energy. Furthermore, in terms of occupant satisfaction, two important features, a feeling of contact with the outside world and creating different work environments, are questioned in the survey. There are concerns about the damage caused not only because of the building construction process with the resource extraction but also because of building operation resulting in high emissions. In consideration of the sustainability perspective, the efficient use of resources was questioned in the survey.

Table 3.3 demonstrates the reference list of features found in the literature. In general, the approach was related with the intelligent design process that combines intelligent architecture, appropriate use of technology, sustainability, and intelligent building services and operation (i.e., facility management processes).

Table 3.3. The referenced articles for each feature for DM

Features included in the survey		References
DM1	Reduction of heating, cooling, lighting, and ventilation load	Glaumann et al., 1999 Chwieduk, 2003 Kolokotsa et al., 2011 Kibert, 2016
DM2	Preparedness of the systems to respond to short-term (demand and supply changes) and long-term (climate change) changes	Chen, 2010
DM3	The integrity of systems in the long term	Wong et al., 2008 Chen, 2010 Clements-Croome, 2011
DM4	Application of natural/passive design strategies instead of active systems	Kroner, 1997 Clements-Croome, 1997 Ochoa and Capeluto, 2008 Kolokotsa et al., 2011
DM5	Reduction/Reuse/Recycle of water	Chwieduk, 2003 ALwaer&Clements-Croome, 2010
DM6	Reduction/Reuse/Recycle of waste	Hartkopf et al., 1997 Hartkopf and Loftness, 1999 Kohler, 1999 Chwieduk, 2003 Chen et al., 2006 ALwaer&Clements-Croome, 2010 Clements-Croome, 2011 Huang, 2014
DM7	Knowledge of the occupant on how the building operates	Wigginton and Harris, 2002 Chow and Leung, 2005 Nguyen and Aiello, 2013 Schmidta and Åhlund, 2018 D'Oca et. al, 2018
DM8	Installation of renewable energy systems (ex. solar, wind and geothermal)	To et al., 2018 Ghaffarianhoseini, 2016 Chwieduk, 2003
DM9	Improved communication for teamwork and collaboration	Yang and Peng, 2001
DM10	Access to outdoor space, both visual and physical	Wyckmans, 2005 Clements-Croome, 2011
DM11	Easy upgrade/renewal of the systems for the advancement of technology	Kua and Lee, 2002 Wong and Li, 2009

Table 3.3. The referenced articles for each feature for DM (cont'd)

Features included in the survey		References
DM12	Easy of space reconfiguration and extension for the changes in size and work practice	Hartkopf et al., 1997 So et al., 1999 Hartkopf and Loftness, 1999 Cho and Fellows, 2000 So and Wong, 2002 Himanen, 2003 Fathian and Akhavan, 2006 Katz and Skopek, 2009 Meistad, 2014 Poppinga et al., 2018
DM13	Degree of the flexibility of façade elements for renovation and future changes	Harrison, 1992 Hartkopf et al., 1997 Clements-Croome, 1997 Kua and Lee, 2002 Buckman et al., 2014 To et al., 2018 Glaumann et al., 2019
DM14	Place allocation to employees according to their preferences or mood	Bordas and Leaman, 1997 Fathian and Akhavan, 2006

3.3.2 Intelligent Building Examples

The experts are asked for a real-world example of IOB in terms of location, size, and construction cost in the survey. Afterward, the information on buildings was collected through the internet to find out the applied features.

CHAPTER 4

A PRELIMINARY STUDY AND SIMULATION TO OBSERVE THE IMPACTS OF SEVERAL BUILDING FEATURES ON ENERGY CONSUMPTION

Before embarking on the analysis of survey results, the findings of a preliminary study are presented in this chapter. It is evident from previous studies that energy efficiency is one of the aspects of intelligence. For the achievement of energy efficiency, two worthwhile questions are raised:

Q1. To what extend the level of technological sophistication is necessary for intelligence?

Q2. What is the role of passive design in building intelligence?

There is a trade-off between the passive design approach and the utilization of technology for active systems. The former consumes zero energy while the latter results in energy consumption. Therefore, to answer these questions, the effectiveness of passive design strategies and active systems for building energy performance was examined. The level of impact of buildings' elements (e.g., wall to windows (WWR), the insulation thickness, glazing type, and type of building systems used) on building energy consumption, is observed in the building energy simulation results.

A number of dynamic building simulations were run with the supervision of a mechanical engineer who has had expertise in building design for more than twenty years. First of all, a shoebox model was considered as an office building in Ankara, Turkey. Then, the optimization steps were followed to improve the building envelope components (passive design approach) and find out the most convenient building systems (active systems) and available renewable energy sources at the building site in terms of energy efficiency and meeting occupant requirements. It is noteworthy that the aim was not to find out the most optimal design for an office building in Ankara, rather indicate the impact of both active systems and passive design approaches explicitly by the simulation outputs in terms of energy consumption.

4.1 The Climate

The climate data were investigated to find out the critical problem for the building performance. According to the Köppen-Geiger climate classification, which distinguishes 25 climate types, Ankara’s climate is in the semi-arid steppe climate zone and described as ‘continental,’ its summer is warm, and its winter is cold. In general, the temperature can drop to below -15°C during the wintertime, whereas it can rise above 35°C during the summertime. The computer model was evaluated for the climate of Turkey, Ankara (39.5 ºN, 32.5ºE) using the IWEC file. Climatic data taken from meteorological stations, often located at airports, was used. However, it should be noted that microclimatic data is more important since the local factors, including its topography and the objects such as trees, buildings around the building, affect the climate factors. As a good base result can be obtained from the psychometric chart, the comfort range indicated in the box most of the points are outside the comfort zone, located on the left, the dominant climatic problem can be evaluated as under heating. This finding helps us identify the passive design strategies for the winter season, giving more importance to passive solar gains and thermophysical characteristics of the envelope. This study used a shoebox model (dimensions 5 x 6 x 3 m) instead of a specified building in the simulations. The dimensions are kept constant at each step of the simulation since the aim is to observe the impact of building envelope and active systems on building energy consumption.

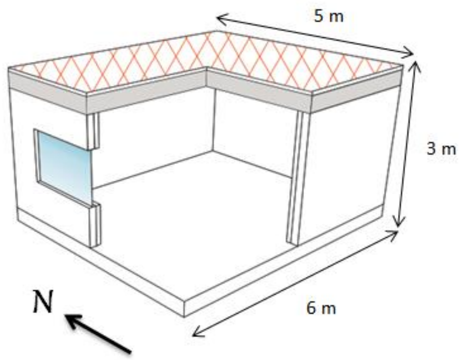

Figure 4.1. The view of the simulated shoebox model

As indicated in Figure 4.1, on the considered model, South - West façade and roof are defined as external, whereas the East-North walls were considered a boundary wall. The longer south-oriented section of the façade has the largest window area with 9m^{2,} and also a window with 7.5m^2 area has been located on the west side. The building's North/South wall is longer than the East/West wall, and the model was oriented towards the south to enhance winter performance by taking advantage of the winter sun. The buildings in Ankara are also north-south oriented.

4.2 The Simulation Methods and Assumptions

The building performance simulations have been performed using Transient System Simulation Tool (TRNSYS). The considered model was established according to Turkish Standards (TS) 825 (2018) since it was a representation of an office room in Ankara, Turkey. The insulation thickness and the details of construction materials for walls, windows, and roofs are described in terms of U-Values, a quantitative measure of thermal transmission. The descriptive information of glazing on the selected type is also presented in terms of U-Values, light, and transmission factors. The simulation parameters defined as TS 825 and the supervision of experienced mechanical engineers, including the thermal characteristics of the materials and the systems, are listed in Table 4.1.

Table 4.1. Parameters for the building energy simulation

General information	
The function of the building Office schedule / Holiday scheme All-day schedule	Office 08:00 – 19:00 / Saturday and Sunday 24 Hours
Envelope properties of base building	
External Wall – South and West Facades	
14.5 W- class brick 4 cm EPS U-value	λ= 0.756 kJ/hr m K λ= 0.14 kJ/hr m K 0.516 W/m^{2}K
Windows – South and West	
U-value g- value T-visible No shading	2.46 W/m^{2}K 0.5 0.6 -
Boundary Wall	
U-value	0.501 W/m^{2}K
Roof	
Concrete 8 cm Glass Wool Bitumen Sand and Gravel U-value	λ= 1.4 kJ/hr m K λ= 0.144 kJ/hr m K λ= 0.61 kJ/hr m K λ= 2.52 kJ/hr m K 0.334 W/m^{2}K
Floor	
U-value	0.4 W/m^{2}K
Internal gains (office schedule)	
People Equipment	2 people - 75 Watt /each 2 computer - 70 Watt / each
Heating (all-day schedule)	
Setpoint temperature – operative Temperature setback (night time)	19°C 1°C
Cooling (all-day schedule)	
Setpoint temperature – operative Temperature setback (night time)	26°C 1°C

Table 4.1. Parameters for the building energy simulation (cont'd)

Ventilation (natural)	
Per person – office schedule Constant Infiltration - all-day schedule	30 m^3/h / 0.7 air changes/hour (ach) 0.2 ach
Lighting (office schedule)	
Lighting (500 lux level)	12 W/m^2

Firstly, reducing heating and cooling load with envelope design is the most important step to downsize HVAC equipment rather than their efficiency. In Turkey, the regulatory requirements for the thermal transmittance of envelope elements, the heat transfer coefficient (U values) in W/m^2K are 0.50 for walls, 0.30 for the roof, 0.45 for ground, and 2.4 for windows as per TS 825 Thermal Insulation Requirements for Buildings in Turkey in which four climate zones are established. Ankara is classified into the third region. A number of simulations were performed to consider each alternative by varying one parameter each time, i.e., windows ratio, the thickness of insulation, type of glazing and shading, type of ventilation indicated in bold in Table 4.2 and 4.3. Since this study focuses on optimizing energy consumption, the evaluation criterion was the final building energy consumption, including heating, cooling, ventilation, and lighting in terms of annual energy use in kilowatt-hours per square meter per annum within a predefined comfort range. The logic was that if the gain is greater than the loss, it is decided as this change is beneficial and used for the next steps.

4.2.1 Passive Design Approach

The characteristics of façade materials significantly impact the building energy performance; thus, the steps followed in the simulations are indicated in Table 4.2, and their details are explained below. To find the optimum combination of alternatives, nine configurations (Table 4.2) were obtained. It should be noted that the output of simulation steps is written for heating, cooling, and lighting energy requirement without knowing from which source it will be obtained; therefore, it does not include supply chain energy losses.

STEP 1 - The model was simulated based on the material properties as per the regulation requirements (TS 825). The fully glazed building with an 85% window to wall ratio (WWR) was considered. WWR is the ratio of the glazed surface to the gross exterior wall area and gives a limit to balance the benefit for daylight and heating potential based on prevailing climate and local topography. This design parameter has the uttermost contribution to the solar heat gain, which has a huge contribution to the heating and cooling load of the building.

STEP 2 - This step tested the influence of window frame with a lower U-value of 0.99 W/m^2K accompanied by exterior glazing with solar heat gain coefficient (SHGC) of 0.251 and visible transmittance (T_{vis}) of 0.502, and that glazing type was chosen apart from the window size, orientation, and shading elements. The results indicated that the heating and cooling energy demand could be reduced with this type of glazing.

STEP 3 - The full-height glazing prevents taking advantage of large exposed concrete surface acting as thermal mass so that interior comfort conditions are stabilized in the heating dominant climates. Therefore, concrete walls with a WWR ratio of 50% ($9m^2$ and 7.5 m^2 window openings) were simulated. The results indicated that even though the use of large glazing surfaces reduces winter heating requirements, it increases the cooling peak energy consumption for summertime. This conceptual envelope was considered as a “base envelope” in this study and used for the comparison of final results since it might be accepted as a standard façade design currently in Ankara.

STEP 4 - The insulation of the base building was located inside; thus, its effect on building thermal performance was evaluated and moved to the outside (on top of the bricks used in walls). The results indicated that both heating and cooling load are reduced.

STEP 5 - The wall insulation has been developed by increasing its thickness from 4 cm to 10 cm and changing the material type from EPS to XPS. Since the materials absorb heat and then transmit it to the next layer, it is of crucial importance that their sequence and thickness affect the timing of this heat transmission. Thus, this transmission can be delayed with good insulation material. The simulation results indicated that heating load was reduced compared to a small increase in cooling load and supported the statement that capacitive insulation controls the timing of heat input, especially in climates with a high diurnal temperature difference; the heat can be stored and released when it is needed (Szololay 2014).

STEP 6 - The effect of an increase in roof insulation from 8 cm to 20 cm was evaluated in this step. The results indicated that since it will reduce heat loss during wintertime, the heating load is less, and against a little increase of cooling demand, it will also reduce the solar gain result in prevention of overheating during the summertime.

STEP 7 - The sun protection glazing type with a g-value of 0.251 and U-value of 0.99 W/m^{2}K was used in the simulation in order to block summer sun. The results indicated that both heating and cooling loads were reduced due to the replacement of improved U-value glazing and a lower g-value, respectively.

STEP 8 - Use of heat protection glazing with a g-value of 0.488 to capture winter solar gain and internal shading such as curtains, blinds to reduce the solar heat input was simulated since while the beam radiation is prevented, the heat is gained by the shading material and distributed to the inside conductively. The results indicated that the heating energy demand was reduced with the passive solar gain strategy during winter, even though the cooling energy demand was doubled.

STEP 9 - The attempt was to reduce the cooling load by introducing external shading by preventing the incident solar gain and thermal radiation to the indoor environment. The results indicated a considerable reduction in cooling load. In contrast, the heating load was increased; this could be resolved by selecting a variable shading element to prevent the sun during the summer without affecting the winter performance. It is also important to design according to the adjustment of luminance level for daylight admission and not obstructing the outside view.

In the final step of the passive design approach, the improved building envelope helped to improve the operational energy performance (heating, cooling, and lighting) compared to the conventional one with WWR (Step 3) designed according to the regulatory requirements as 52% of heating and 75% of cooling demand decreased while 15% of electricity (only for lighting) demand increased. On the other hand, if the improved envelope is compared with the fully glazed building in Step 1, there is considerable energy saving. The fully glazed building case has led to worse performance due to the higher energy losses in the heating-dominated climate.

Table 4.2. The results of simulation steps for the optimization of the building envelope in terms of final energy consumption

Steps	Name	WWR	Window/Glazing	Wall Insulation	Roof Insulation	Shading	Energy load (kWh/m2/year)
1	Fully glazed building	85 %	U=2.46 W/m^{2}K SHGC (g-value) =0.599 T-sol = 0.515 T-vis=0.601	from inside 4 cm EPS U=2.5 W/m^{2}K	from outside 8 cm glass wool U=0.334 W/m^{2}K	no element	$Q_{heating}$= 114.12 $Q_{cooling}$= 139.51 $Q_{lighting}$= 5.30
2	Using sun protection glazing	85 %	**U=0.99 W/m^{2}K** **SHGC (g-value) =0.251** **T-sol = 0.241 T-vis=0.502**	from inside 4 cm EPS U=2.5 W/m^{2}K	from outside 8 cm glass wool U=0.334 W/m^{2}K	no element	$Q_{heating}$= 73.66 $Q_{cooling}$= 54.73 $Q_{lighting}$= 5.49
3	Decreasing WWR to 50% (Base envelope)	**50%**	U=2.46 W/m^{2}K SHGC (g-value) =0.599 T-sol = 0.515 T-vis=0.601	from inside 4 cm EPS U=2.5 W/m^{2}K	from outside 8 cm glass wool U=0.334 W/m^{2}K	no element	$Q_{heating}$= 83.85 $Q_{cooling}$= 75.56 $Q_{lighting}$= 5.68
4	Moving the insulation to the exterior	50%	U=2.46 W/m^{2}K SHGC (g-value) =0.599 T-sol = 0.515 T-vis=0.601	**from outside** 4 cm EPS U=2.5 W/m^{2}K	from outside 8 cm glass wool U=0.334 W/m^{2}K	no element	$Q_{heating}$= 81.00 $Q_{cooling}$= 72.26 $Q_{lighting}$= 5.68

Table 4.2. The results of simulation steps for the optimization of building envelope in termfinal energy consumption (cont'd)

Steps	Name	WWR	Window/Glazing	Wall Insulation	Roof Insulation	Shading	Energy load (kWh/m2/year)
5	Increasing the thickness of wall insulation	50%	U=2.46 W/m^2K SHGC (g-value) =0.599 T-sol = 0.515 T-vis=0.601	from outside **10 cm XPS** **U=0.259 W/m^2K**	from outside 8 cm glass wool U=0.334 W/m^2K	no element	$Q_{heating}$= 73.29 $Q_{cooling}$= 73.95 $Q_{lighting}$= 5.68
6	Increasing the thickness of roof insulation	50%	U=2.46 W/m^2K SHGC (g-value) =0.599 T-sol = 0.515 T-vis=0.601	from outside 10 cm XPS U=0.259 W/m^2K	from outside **20 cm glass wool** **U=0.167 W/m^2K**	no element	$Q_{heating}$= 64.28 $Q_{cooling}$= 75.56 $Q_{lighting}$= 5.68
7	Using sun protection double glazing	50%	**U=0.99 W/m^2K** **SHGC (g-value) =0.251** **T-sol = 0.241 T-vis=0.502**	from outside 10 cm XPS U=0.259 W/m^2K	from outside 20 cm glass wool U=0.167 W/m^2K	no element	$Q_{heating}$= 45.36 $Q_{cooling}$= 32.37 $Q_{lighting}$= 6.09
8	Using heat protection glazing and internal shading	50%	**U=0.98 W/m^2K** **SHGC (g-value) =0.488** **T-sol = 0.424 T-vis=0.725**	from outside 10 cm XPS U=0.259 W/m^2K	from outside 20 cm glass wool U=0.167 W/m^2K	internal shading	$Q_{heating}$= 33.24 $Q_{cooling}$= 63.42 $Q_{lighting}$= 6.69
9	Using heat protection glazing and external shading	50%	U=0.98 W/m^2K SHGC (g-value) =0.488 T-sol = 0.424 T-vis=0.725	from outside 10 cm XPS U=0.259 W/m^2K	from outside 20 cm glass wool U=0.167 W/m^2K	**external shading**	$Q_{heating}$= 40.58 $Q_{cooling}$= 19.05 $Q_{lighting}$= 6.69

4.2.2 Active Systems

Heat flow into and out of buildings is driven by two climatic elements, air temperature difference and solar radiation. Therefore, using the natural movement of both air and heat to maintain comfortable temperatures and operating with little or no mechanical assistance was the main idea of active system optimization in the simulation steps. It should be noted that ventilation requirement was generally taken as a function of occupancy density; in this case, since there is no real occupancy information, 30m^3/h per person was taken into consideration. The details of the simulation steps are indicated in Table 4.3.

STEP 1 - The fan coils are preferred for heating and cooling purposes in the offices because they provide high individual control ability for the interior climate. They consume a high amount of electricity that was added with an amount of 4W/m^2 per hour during the heating/cooling system operation hours. The attempt was to conserve energy by lowering the room temperature to a reasonable level in the simulation that 19ºC for heating would be adequate in wintertime whilst 26ºC for cooling, which is comfortable enough in summer time. In this way, extra energy savings were achieved. As a first scenario, the base envelope in the third step of the passive design approach was used in the simulation where fan coils for heating and cooling purposes with mechanical ventilation and heat recovery were installed as active systems. It should be noted that this way of design in this step is a common approach for many designers in Ankara; thus, this conceptual model can be considered as a base building and used for the comparison of final results.

STEP 2 - The improved envelope in step nine of passive design approach simulations (Q heating= 40.58, Q cooling= 19.05, and Q lighting= 6.69 in kWh/m^2, year) was used to build upon the active systems for heating, cooling, and ventilation requirement of the building. As previously mentioned, the simulations in the passive design approach were run according to the scenario of natural ventilation, and the electricity consumption was only due to the lighting. Therefore, the fan coils were included as a heating and cooling system into the simulation at this step, and results indicated a considerable increase in the electricity consumption.

STEP 3 - The mechanical ventilation with a rate of 0.75 sensible heat recovery to control the temperature, humidity and purification of the air change was evaluated in the simulation. The results indicated that the electricity consumed by the ventilation system increased by almost 10 kWh/m^2. An important outcome was that because the temperature difference is not so low in winter (ambient temperature), mechanical ventilation with a heat recovery system is not working so well for this climate.

STEP 4 - Use of hybrid ventilation, sometimes so-called mixed-mode ventilation, provides outside air by both passive (naturally ventilated by operable windows or earth duct) and mechanical (an air distribution system with refrigerant or heating system) means. The aim was to reduce the electricity consumption of the mechanical system, and the results supported this aim with a reduction of 4.38 kWh/m^2.

STEP 5 - Due to the disturbance of direct cold airflow during summer or hot airflow during winter and high energy consumption, an active slab strategy was applied together with hybrid ventilation. The results indicated that the electricity consumption was reduced although heating and cooling energy demand increased dramatically.

STEP 6- Taking advantage of high diurnal temperature difference of this climate, night ventilation strategy was applied. The simulation results indicated that the cooling demand during the day could be reduced with this natural strategy without any additional cost. A building constructed with heavy materials, so-called thermal mass shall have more heat capacity than light construction materials. Thermal mass refers to the high heat capacity materials that can absorb heat, store it and release it later (Sadineni et al., 2011). The concrete slab is left exposed to the air to activate thermal mass, and heat/cold can be stored. Thermal mass, in the form of massive building elements, also supports the night ventilation where concrete slabs are activated with the cold airflow. In order to increase thermal contact with the structure, no suspended ceiling should be used. By using this as a strategy, the heat gained during the day is purged from the building, and cool night air during summer days can help reduce the peak cooling demand, and that heat gained on sunny days in winter can help keep the building warm for the following cold night. The results indicated a reduction of approximately 3 in kWh/m^2 in a year in cooling energy demand.

STEP 7 - In the final step, an active slab with embedded pipe coils was used for radiant heating and cooling of the environment together with the night cooling strategy and natural ventilation. Given Ankara's climate, ventilation could be achieved through natural ventilation without additional energy burden.

Instead of fan coil systems, a radiant heating or cooling system (active slab system) achieves more than 50% of its space heating or cooling by radiant (as opposed to convective) means. Generally, radiant systems minimize fan energy and enhance comfort by conditioning the space via an increased/decreased surface temperature. Thus, the active slab system is more energy-conservative and comfortable. Warm/cool water is circulated through the tubing to maintain the slab surface temperature above/below the desired room operative temperature. The thermal mass of the system causes the slab temperature to vary slowly, with the water flow often being turned on and off only once per day. Mean radiant temperature is a weighted average of the temperatures of all the surfaces in a direct line of sight of the body (Bradshaw, 2006). A large portion (50-80%) of the structural slab, therefore, must be directly exposed to the room and the occupants for this system to be effective. Because direct radiant exchange plays a critical role, the angle of the body's 'view' to the active slab or radiant panel should be maximized by removing obstacles, such as furniture. As a result, the energy consumption trend illustrated that the optimized building in Step 7 could provide perfect comfort conditions while providing 25% heating demand saving, 70% cooling demand saving, and 56% electricity saving compared to the base building in Step 1.

Table 4.3. The results of simulation steps for the optimization of active systems in terms of final energy consumption

Steps	Name	Heating / Cooling	Ventilation	Energy load(kWh/m2/year)
1	Base building envelope with systems installed (base building)	**Fan coils** Set point temperature for heating =19ºC Set point temperature for cooling =26ºC	**Mechanical Ventilation with heat recovery** Supply temperature in winter =18ºC Supply temperature in summer =21ºC Sensible heat recovery =0.75	$Q_{heating}$= 87.32 $Q_{cooling}$= 91.15 $Q_{electricity}$= 47.99
2	Improved building envelope with systems installed	**Fan coils** Setpoint temperature for heating =19ºC Setpoint temperature for cooling =26ºC	Natural Ventilation	$Q_{heating}$= 40.58 $Q_{cooling}$= 19.05 $Q_{electricity}$= 35.69
3	Mechanical ventilation with heat recovery	Fan coils Setpoint temperature for heating =19ºC Setpoint temperature for cooling =26ºC	**Mechanical Ventilation with heat recovery** Supply temperature in winter =18ºC Supply temperature in summer =21ºC Sensible heat recovery =0.75	$Q_{heating}$= 38.27 $Q_{cooling}$= 20.92 $Q_{electricity}$= 44.63
4	Hybrid ventilation	Fan coils Setpoint temperature for heating =19ºC Setpoint temperature for cooling =26ºC	**Hybrid Ventilation** Outside temperature above=9ºC Outside temperature below=30ºC	$Q_{heating}$= 38.66 $Q_{cooling}$= 21.16 $Q_{electricity}$= 40.25

Table 4.3. The results of simulation steps for the optimization of active systems in terms of final energy consumption (cont’d)

Steps	**Name**	**Heating / Cooling**	**Ventilation**	**Energy load (kWh/m2/year)**
5	Active slab	**Active slab** Setpoint temperature for cooling=24ºC Setpoint temperature for cooling=21ºC	Hybrid Ventilation Outside temperature above=9ºC Outside temperature below=30ºC	$Q_{heating}$= 62.79 $Q_{cooling}$= 31.70 $Q_{electricity}$= 24.11
6	Active slab, night cooling	Active slab Setpoint temperature for cooling=24ºC Setpoint temperature for cooling=21ºC **Night cooling**	Hybrid Ventilation Outside temperature above=9ºC Outside temperature below=30ºC	$Q_{heating}$= 62.79 $Q_{cooling}$= 28.86 $Q_{electricity}$= 24.08
7	Optimized building	Active slab Night cooling	**Natural Ventilation**	$Q_{heating}$= 65.44 $Q_{cooling}$= 27.54 $Q_{electricity}$= 21.02

4.2.3 Primary Energy Use

The energy sources can be fossil fuels: coal, oil or gas, or electricity produced from nuclear or hydropower, or renewable energy sources such as solar, wind, or geothermal. The most important earlier energy source was coal, but the start of oil production changed the lifestyle of people in the early twentieth century. Shallow earth temperature fluctuates with seasonal outside air temperature, and earth temperature becomes more stable with increasing depth (almost constant after the depth of 2-3m throughout the year at about the annual mean air temperature of the location). The temperature is around 12°C for Ankara. Geothermal energy, defined as “energy from the internal heat of the earth,” can be used, and this energy source is independent of weather conditions, seasons, and times of day and of increasing the price of fossil fuels. Moreover, it can be used all year round for heating in wintertime and cooling in summer time.

Gustafsson et al. (2016) stated that the different perspectives exist for the indicator for energy efficiency of a building in terms of primary energy factor value or final energy; however, primary energy is only one way to evaluate the energy and resource consumption. As kilowatt-hours could not be compared without taking the energy source into account (Glaumann et al., 1999), the simulation outputs were converted using primary energy factors (PEFs). In order to calculate primary energy demand, the Coefficient of Performance (CoP) values were taken as 1.1 for a gas boiler, 3.0 for chiller and 4.0 for heating, and 30 for cooling for the active slab system. The selection of high-efficiency equipment for HVAC and other systems is one way to achieve energy efficiency. The common way to provide energy is from fossil fuels, like electricity and natural gas, since chiller and gas boilers are used for cooling and heating. In this regard, the total building energy demand was converted into electricity by using CoP values, and then the cooling and electricity load values were multiplied by 3.0, and the heating load value was multiplied by 1.1 as the primary energy factor. The reference to the statement by Szokolay (2014) that in conventional coal-fired electricity generation are unit of electricity is equivalent to three units of primary energy. The results revealed that optimized building has almost 64% energy saving in terms of primary energy use than base building.

4.3 Summary of the Results

Cold is the climatic constraint for Ankara due to low temperatures, and also, since the temperature difference between the inside and outside is high, thermal insulation of the envelope is the most effective strategy to control the heating requirement of the building. The critical points obtained from the results of design optimization steps for an office building in Ankara are summarized below, aside from the importance of climate data analysis to understand the local conditions.

For passive design approach:

- The high insulation level is inevitable because the outdoor temperature drops below zero.
- The most effective passive strategy is the reduction of WWR ratio (%) and external shading, especially on the south-façade during the heating periods and followed by the night ventilation via the activated thermal mass.
- The use of windows with low thermal transmittance and high solar transmittance glazing was better in winter; however, high solar gain worsens the summer cooling performance.

For active systems:

- The active slab radiant system with heat pump system by using geothermal energy reduced the energy consumption considerably compared to the used systems in a typical building.
- Instead of using high-tech air conditioning systems, the combination of strategies, a high thermal mass with night cooling, helped the reduction of cooling load by getting the advantage of temperature differences between day and night; bare concrete surfaces abate the heat gained throughout the day in summer.

- The energy source from the renewable ones added value to the environmental building performance.

The compared results with the conventional buildings indicated a saving of 64% in terms of primary energy use and 25% heating demand saving, 70% cooling demand saving, and 56% electricity saving compared to base building in terms of final energy use. This encourages the designers to prefer the application of more passive strategies.

In conclusion, it is noteworthy that the optimized building does not represent the ideal case for building design considering the climate conditions of Ankara; rather, it indicated the importance of design parameters, passive design approach, and utilization of active systems in response to the micro-climate conditions. The simulation model results have helped determine the IB features that evaluate the building intelligence in terms of reducing building energy load with passive approaches (natural design strategies) instead of active systems. Energy-saving effects of passive measures should be considered early in design since the implementation of passive design strategies accrues more benefits to the energy performance of the building. Therefore, the features related to the passive measures are included in the survey.

CHAPTER 5

FINDINGS OF THE EXPLORATORY SURVEY

This chapter presents the analysis of findings on the characteristics of IBs through the viewpoints of professionals working on this area and case buildings being considered as ‘intelligent’ at present. To begin with the data analysis, the time spent on the questionnaire was used as a filter to select a reliable response as the same method in the study of Toft et al. (2014). Accordingly, the average survey completion time was calculated as nineteen minutes. Since writing a response for open-ended questions could take more time, the respondents who answered the open-ended questions completed the survey in approximately twenty-five minutes. Hence, three responses less than five minutes were not included in the evaluation. A final sample of sixty-seven participants who had completed the whole questionnaire were accepted.

5.1 Findings of the Focus Group

Before the survey was distributed, a focus group study was performed to assess the content and the format of the survey questions. The demographic information of experts, who attended the focus group is demonstrated in Table 5.1. All of the mechanical engineers and two architects have experience of more than ten years, whereas two of the architects have experience of between three to five years. Sitting around a table, each participant went through the survey by giving comments for each feature and also questioning the general design of the survey.

Table 5.1. Focus group participants' information

No.	Expertise	Age	Nationality	Experience
P1	Mechanical Engineer	57	German	More than ten years
P2	Architect	40	German	More than ten years
P3	Mechanical Engineer	42	German	More than ten years
P4	Architect	38	Canadian	5-10 years
P5	Architect	29	Albanian	1-3 years
P6	Architect	28	Egyptian	1-3 years
P7	Mechanical Engineer	28	Chinese	1-3 years

Firstly, comments were related to the general layout of the questionnaire that whether the definition of IBs summarized from the literature should be given or not at the beginning of the survey. Then, it was decided that instead of providing the definition, letting the participants create their own definitions by using the features in the questionnaire would be better. Secondly, some features were evaluated as being very wide and general, while others were found to focus on more specific aspects of IB. After some discussion, some features were excluded. Indeed, the features that is a must and exists in the related building legislation and regulations, such as earthquake design considerations and applications as per the fire safety code were excluded due to the fact that they also vary according to the countries. The excluded features are "special design considerations for disabled and elderly," "special design for the natural disasters (flood, earthquake, etc.), "easy reach to high-speed local network" and some features of BMS such as structural monitoring, energy, and water usage monitoring, space, and humidity monitoring. Thus, only the parameters related with building intelligence or beyond the Turkish legislation were included in the survey. Lastly, expert P7 considered some features (e.g., reduction of water or occupant participation to the design process) as unnecessary and commented that "not related with technology." P2 stated that the feature of recycling is not related with the IB concept. From these comments, it was understood that some experts considered the

IB concept only from technology point of view; however, these features are kept in the survey since the sustainability aspect is also evaluated in this thesis. Further, the participants spoke about the project phases, and the “pre-design phase” was defined as the time when the simple conceptual drawings are prepared. Therefore, in the survey, the evaluation of IB features was considered to be the design phase when all the experts, electrical, mechanical, structural engineers, and architects came together and evaluated all aspects of the design to solve the technical intricacies faced during the innovative strategies development. The extent of this thesis on the intelligent building concept is limited to its features that were confined to Advanced Systems (ADV), Building Management Systems (BMS), and Design Management (DM).

During the study, some controversial opinions on how much technology is needed to be integrated into the design were expressed. P1 stated that it is crazy and not necessary to control everything with a device such as a smartphone. Moreover, she explained her concern as giving information and data about herself to the world makes her feel insecure. On the other hand, P7 argued that IBs should do things that people cannot do with the help of AI. Finally, P5 and P6 were concerned about the features related to the flexibility in buildings since a variety of ways, concepts, and solutions exist. The participants with varying preferences and ages interpreted the IB concept differently. Ultimately, the focus group contributed very useful insights into the process of survey development.

At the end of the focus group study, the time taken to complete the survey was calculated, which was around fifteen minutes, and based on collected feedback and suggestions, the questionnaire survey was modified in terms of wording and removal of some general features so that it would be easily understood by the wider participants and in terms of comprehensiveness of the questionnaire. Removing the six features from the draft survey, 37 features of the IBs were found important in determining the intelligence level of an office building.

5.2 Analysis of Questionnaire Results

The dataset for the analysis used in the study was collected through a questionnaire completed by sixty-seven participants from different disciplines, such as smart cities advisors, climate engineers, and marketing managers. The sample size was calculated using the formula provided in the study of Park and Jung (2009), and the result indicated a sample size of 53 in order to have adequate power for the representation of the population with the tolerable error of 10 %. Therefore, the number of participants met the required sample size. The main demographic characteristics of the experts are shown in Table 5.2. Among the respondents, architects represent 36% of the sample; a similar percentage corresponds to design consultants as the expertise of participants. The professionals were classified as "others" who are smart cities advisors, two real estate advisors, four climate engineers, two market managers in the construction material industry, aerospace engineers, a geological engineer, two indoor climate engineers, an environmental engineer. In response to the professionals' experience, the experts having 3-5 years and more than ten years of experience in the built environment was a percentage of nineteen and fifty-five, respectively. Then, in order to classify the views of experts in different regions of the world, the nationality of experts is categorized according to the continent where they live. As such, the experts from Asia represents 42% of the sample, specifying the countries as New Zealand, Turkey, Indian, Chinese, Australia, and Singapore and 33% of the respondents from Europe, i.e., Germany, Denmark, United Kingdom, France, Italy, Belgium, and Switzerland. Moreover, American experts were from USA and Canada, and African experts were from Nigeria and Ethiopia. Finally, in terms of their place of experience, if the expert has experience in different continents, such as in Asia and Europe, it was accepted that the expert has worldwide experience. Within this context, 56% of them has worldwide experience, to elaborate the place of countries, for instance, one expert has experience in all of western Europe, UK, Iceland, H, Croatia, Slovenia, USA, CAN, Mexico, Caribbean Islands, China, Singapore, Malaysia, Australia, NZ, Tunisia, and another expert stated the countries as Germany, US, Canada, France, Austria, Switzerland, China, India, Netherlands, UK, Croatia. In short, the sample of the survey is quite broad in terms of experience, discipline, and nationality; hence, generalization of intelligence definition for the building could be made.

Table 5.2. Questionnaire survey participants' information

Profession		**Percentage**
	Civil Engineer (N=11)	16%
	Mechanical Engineer (N=12)	18%
	Architect (N=24)	36%
	Other (N=20)	30%
Expertise		
	Designer (N=18)	27%
	Design Consultant (N=24)	36%
	Researcher (N=18)	27%
	Other (N=7)	10%
Experience		
	0-3 years (N=8)	12%
	3-5 years (N=13)	19%
	5-10 years (N=9)	13%
	More than 10 years (N=37)	55%
Nationality		
	Asian (N=27)	42%
	African (N=6)	9%
	European (N=23)	33%
	American (N=11)	16%
Place of experience		
	Asia (N=15)	23%
	Europe (N=7)	11%
	America (N=3)	5%
	Africa (N=4)	6%
	Worldwide (N=37)	56%

5.2.1 Open-ended Questions

The first question 'How do you define an intelligent building? Based on your personal experience, what features are necessary to denote an office building as "intelligent"?' was asked to the professionals in order to reflect their personal definition of *intelligence* in buildings. The responses revealed that "responsiveness," "automated," "occupant centered design," "climate-based design," and "real-time monitoring" are the most associated features of IB.

First of all, among sixty-seven experts, seven of them did not provide an answer in this part. One of the experts expressed that using the term "intelligent building" is a hype that discourages thoughtful design. An expert from America advised to use of the term "high-performance building," and another American expert expressed that the term "intelligent" is a bit dated; hence the buzz word "smart building" should be used. As also explained in the literature review chapter, these terms became almost synonymous with the IB. On the contrary, one respondent argued that attaching a functional name to a building could limit its life and thus its sustainability. That's why; one of the thesis objectives is to understand the varying use of adjectives used for buildings.

Another research participant provided a comprehensive definition of the IB which provides:

- *"operational and cost-effectiveness, advanced digital infrastructure and control systems, remote connection and management, performance monitoring and benchmarking systems for its owners or administrators,*
- *indoor environment quality, optimum comfort, demand responsiveness, advanced digital infrastructure, occupational and health safety and for its occupants,*
- *benchmarkable data, flexible and adaptable infrastructure with sustainable city strategies and practices for public administration such as municipalities and/or central government institutions, NGOs ,etc".*

A European market manager and also as being an architect wrote the definition as "*there is no "intelligence" in dead matter like material, construction, etc. It is about the exchange between people (designer, builders, user, etc.) with their tools (computer, software, network, etc.) and their environment (desk, office, building, etc.) that make "a building" "intelligent." Intelligence cannot be stuck into a certain feature, such as sensors being in the market; intelligence is a constantly and vivid search for optimized processes which is not linear and not necessarily efficient but always effective in a particular situation. In that sense of "designing the process of life," features that denote an office building as "intelligent" are quite holistic:*

- *multi-comfort: thermal, acoustical, safety, aesthetics, sustainability, and time performances*
- *tracking: of used products and materials with production data along all stakeholders throughout the life-time of a building*
- *measuring: of temperature, humidity, outside wind conditions, fine dust, rain, alarm with steering the building accordingly or making it an interactive part of larger (urban or campus) network*
- *energy: making it a power supplier and thus part or a network*
- *communication: providing online building services, monitoring"*

As a general definition provided by an Asian architect as *a building that provides a productive and cost-effective environment through optimization of its four basic elements including structures, systems, services, and management.*

As Table 5.3. illustrates the keywords mentioned in the expert's answers to the open-ended questions, and each word being a feature or characteristic of IB is explained in the following paragraphs.

Table 5.3. Answers to the question of the definition of IB

Keywords from the IB definition in the responses	Number of times
Occupant centered design methodology	22
Automated (Operation itself sensing the environment and automated adaptation)	19
Energy efficiency	18
Responsiveness (Reactive capacity to adjust building elements for changing conditions)	17
Advanced Technologies (Latest and smart technology)	13
Climate based design (Passive functionality)	13
Real-time monitoring (Environmental conditions and occupant behavior)	12
Sustainability	11
Less technology	10
Intelligent building monitoring and control system	10
Remote control of smart features	10
Smart use of resources	7
Learning ability and prediction of occupant preferences	6

The idea of IBs is mainly associated with ***"responsiveness,"*** according to the comments of many experts. This characteristic property of IB has a very general meaning, such as being responsive to its environment, climate, economy, and social requirements where it is being built. As one of the experts expressed that an intelligent office building is responsive (1) when it is designed to address the local climate in which it is located and (2) when it is designed by replacing the users at the center of the design. One of the experts explained as responding to the life happening inside it continuously. In the same vein, it was stated that an IB should always proactively respond the environmental changes and occupant demands with its adaptive building management system. Another expert stated that an intelligent building responds to its context in physical, operational, social, and environmental terms with the connection to its surroundings. This comment means that despite all changes happening in external environmental parameters (e.g., daylight, heat) per time, energy consumption and optimal comfort level of the building shall not be affected. In other words, the building shall adapt itself to the environment by means of interacting with the immediate environment. Hence, it is noted that a traditional building is generally a static and inanimate object, while IBs are able to adapt the building systems and façade elements in response to the variations of occupancy, climate, and seasons. That brought the feature of **"a*utomated"*** into the definition of IB, especially for automation of building technology, such as HVAC, lighting, and security systems with the use of various sensors and actuators. In the responses, 'operation itself,' 'automated adaptation to target parameters and required services,' 'automatically control of the operations,' 'automation in various mechanical, communication, and electrical systems,' and even 'automated comfort' are mentioned. Furthermore, a researcher has defined the IB as the one that has most of its accessories, such as lighting, retina scanners, and voice recognition, automated by incorporating smart technologies.

In response to the amount of building automation which makes every decision itself without giving any control to the user, ***"occupant centered design"*** methodology was mentioned in many responses, mainly pointing out the meeting occupant's requirements with the consideration of their comfort satisfaction and especially, their health and wellness will be important because of the infectious diseases like Covid-19. A consultant expressed that each building has a specific purpose and behavior requirement, and the intelligence embedded must cater to this in a certain bespoke manner which may be a combination of general and specific requirements. In this regard, the expert who worked both in India and United States provided a good explanation on balance between automation and user control as follows:

> *"First and foremost, an intelligent building should ideally encourage (and create) intelligent users that operate and occupy the building the way it was (or even better than) intended by its designers. It must, at a minimum, provide optimum daylight, natural ventilation and connection to the outdoor environment for all occupants. A prevalent notion that smart/intelligent buildings are heavily automated is detrimental to the*

creation of truly intelligent buildings of the future. The intent of any intelligent building should be to provide users with control over their environment, not to take it all away by a building automation system. Automation is absolutely required, but only in specific situations with a specific purpose. Intelligent building should use minimum natural resources to provide optimum comfort to all users."

It is clear that only the use of automation is not considered 'intelligent'. The importance of user interaction with the building services, such as ventilation, conditioning, controls of lighting and solar shading, and information about the building consumption through transparent and real-time energy metering is also mentioned by a number of experts.

Under the light of the definitions above, the ability to respond to the occupants' needs through optimization of the systems, the services, and the management is being achieved with the help of technology. Since intelligence, being mainly AI, was generally associated with the integration of ***"advanced technology"*** in people's minds, it is given as another feature under the IB definition. For instance, speaking of the benefit of the IoT in buildings, ***"remote control of smart features"*** was noted in the responses as 'working online,' 'having objects connected to each other on a network so that one may control things remotely.' One of the experts stated that an intelligent office should have remote systems in my opinion (to be controlled by mobile apps) for controlling HVAC equipment, security systems, and similar smart features to decrease the operating cost of the office that the operation heavily relies on using high-tech devices for many hours since the cost of electricity may be the main concern for the companies. Moreover, when it comes to all the technological advancements such as the IoT, integration of smart appliances and sensor-based technology in the built environment for operation and management, thereby enabling maximum controllability of building systems and façade elements are also expressed as ***"intelligent building monitoring and control system"*** in the survey. For instance, two American respondents stated that the reactive capacity of the building could be ensured with the incorporation of a control system that responds to more than just indoor and outdoor temperatures. In addition, having a commissioner BMS system shall allow full control of the building systems and coordination of different building systems. Within this context, continuous collection and analysis of the data in order to give appropriate solutions, which is a characteristic part of being responsive, becomes a necessity. As such, ***"real-time monitoring"*** of a building was stipulated in the responses many times since the sensor technology enables the data collection of energy, water consumption, occupancy in terms of presence, preferences, health-wellbeing metrics, and space utilization during the day and night time. As expressed by a design consultant, full tracking of data on a real-time basis helps achieve well-defined "desired outcomes" that are minimal use of energy and water, GHG emission reduction targets and carbon-neutral targets. One of the experts proposed the use of online applications to extract real-time operating data from Building Management Systems (BMSs) and to use the analyzed data for real-time management decisions. Overall, at its most basic, an intelligent building is one that uses technology to share the collected information between systems (from heating and ventilation to air conditioning and security) so as to get the optimum building performance. A consultant with more than ten years of experience argued that although building overhead cost is of significant business expense for any building owner/user, the level of spend is often wasteful because it's not intelligently applied. For instance, the lights may be on in unused rooms or spaces heated when there are no people around to enjoy the warmth. In this regard, the main motivation behind the intelligent building is to avoid this kind of wasteful use of energy and resources, both in terms of cutting the cost and improving energy efficiency. Accordingly, the ***"learning ability"*** feature comes into the definition as another prominent feature that is the result of analyzing the real-time data and giving reasonable responses for the benefit of both occupant and energy efficiency targets of the building. In the responses provided, it was noted that an intelligent building learns the preferences and comfort levels of occupants and predicts user needs with feedback loops in order to create a comfortable environment with minimized energy demand. In other words, the building notes the number of people and their preferences and responds by adjusting lighting, temperature control, and window sun control with the consideration of the zone consumption and overall building power load and, if present, renewable energy production (i.e., photovoltaic panels). As a summary with the features of IB written so far, a design consultant provided the definition as "*a building that is adaptive to its surroundings; to its interior use: how many people are using it at the moment, what is the room climate, what lighting conditions are required and to exterior conditions: climate, solar radiation by mainly through connected hardware (IoT) and AI algorithms continuously learning from the use of a building and improving its operations accordingly leading to cost and energy savings.*"

"Energy efficiency" was taken as another emphasis in the responses by stating 'minimizes excess use of energy', 'energy saving', 'smart saving of power,' 'minimum use of energy', 'minimized energy demand' and 'energy-efficient technology'. On the one hand, as highlighted in the experts' comments, the main aim of integrating technology that provides solutions for being adaptive to environmental stimuli is to improve the building performance in terms of energy consumption and create a safe, comfortable and productive environment. On the other hand, an Asian designer commented that an intelligent building is the one that uses resources carefully and orients itself to the site conditions making most of what is available and blocking all undesired outside conditions. The expert also shared his/her experience by stating that "I have worked in an open office where minimally processed materials were used and are passively ventilated, and I found those buildings like that intelligent even though it doesn't have any sensor or complex system; that is said I feel active systems don't necessarily mean a building is not intelligent and the resources being used wisely is the underlying concern." Therefore, in this drawn framework, it is understood that the utilization of advanced technology does not necessarily make a building 'intelligent'. That's why the notion of ***"climate-based design"*** introduced a number of times were described by a consultant who worked in different countries that the building on its own, without any big technology, works as a thermodynamic organism and maybe an intelligent building control system could support the building for an adaptive response; however, it is a good point for discussion during the integrated design process which is the key. This is also affirmed by a mechanical engineer from Europe that intelligent building maximizes the use of passive functionality and only uses technical solutions supportive. The passive design approach was also stressed out by an Asian architect that passive environmental features should be included at the start and followed by low energy services, light sensors, recycling air conditioning systems, water capture, monitoring energy use, and adjusting all services and finally, throughout the inclusion of biophilia, the establishment of a natural environment as much as possible. Therefore, the reduction of consumption which is achieved with the building codes in some countries, is the first step and then the design of equipment to meet the loads, i.e., heating, cooling, and lighting. The experts proposed some strategies which are using internal gains, especially from the IT, to heat the building, use of heat pump(s) and chillers in combination with geothermal /foundation piles/wastewater heat exchanger/ice storage if possible. Further, in the answers, 'climate adaptive' 'climatically responsive fenestration' 'climate-responsive building structure and envelope to achieve a high user comfort at low environmental impact' were expressed, and as a design consultant from Europe put rather simply that a building can't be intelligent; it is the design of the building, which is intelligent. This implication from the overall comments indicates that an intelligent building takes advantage of natural forces, i.e., sun heat, daylight, air with a high focus which shall minimize the systems rather than the utilization of advanced technology. In the view of this contemplation, the idea of ***"low technology"*** is noted in the form of 'low-tech,' 'the simpler the better,' 'low-tech solutions,' 'less technology' and 'working with minimum technical installations and controls.' A researcher from Europe elucidated that all the technology used in a building should have a precise purpose; it should not be used as a budget because too much nonsense technology always ends up in little benefits for efficiency or user operation. This statement was also underlined by three experienced professionals by saying that "less technology in terms of MEP is more," "installation of only the real necessary equipment," and "using low-tech solutions can also make buildings very adaptable too with the additional benefits of being simple, robust and easy to understand as much as possible." As a result, it can be said that an IB may or not be a high-tech building.

The building design principles are generally based on a set of functional and aesthetic objectives; however, ***"sustainability"*** became a decision criterion to evaluate the economic, social, and environmental conditions. Moreover, as stated in the previous chapter, intelligent buildings should promote sustainability throughout their lifetime. In response to the IB definition, two experts denoted the IB as a sustainable building that is cost-effective, energy-effective, and water-effective. They pointed out the importance of sustainable design considering the environment to address comfort issues with as little energy and less carbon footprint as possible. In the same vein, ***"smart use of materials"*** is mentioned six times by the experts with the explanation of minimum use of resources, materials, electricity, working hours for operation while providing the required services of buildings. Moreover, the 'resilient' and 'flexible' are mentioned one time in the responses as one of the IBs' characteristics.

Table 5.4. shows that those who considered "occupant centered design methodology" important also mentioned "energy efficiency", and so is the most frequent pair of keywords, followed by "occupant centered design methodology" with "sustainability" and with "automated" mentioned together seven times; "responsiveness" accompanied with "automated" seven times.

Table 5.4. The number of keywords mentioned together in the survey

Keywords from the IB definition in the responses		
Occupant centered design methodology	Energy efficiency	12
	Sustainability	7
	Automated	7
	Intelligent monitoring and control	6
	Remote control	5
	Responsiveness	6
	Climate based design	6
	Advanced technology	4
	Learning ability/ prediction of occupant preferences	3

Table 5.4. The number of keywords mentioned together in the survey (cont'd)

Keywords from the IB definition in the responses		
Automated	Responsiveness	7
	Occupant centered design methodology	7
	Energy efficiency	6
	Advanced technology	4
	Climate based design	3
	Real-time monitoring	3
	Sustainability	3
	Intelligent monitoring and control	3
	Remote control of smart features	3
Climate based design	Low technology	6
	Occupant centered design methodology	6
	Energy efficiency	5
	Automated	3
	Sustainability	3
	Intelligent monitoring and control	3
Energy efficiency	Occupant centered design methodology	12
	Automated	6
	Responsiveness	5
	Climate based design	5
	Intelligent monitoring and control	4
	Real-time monitoring	4
	Smart resource use	4
	Advanced technology	3
	Remote control of smart features	3
	Sustainability	3
	Learning ability and prediction of occupant preferences	3
Advanced technology	Automated	4
	Occupant centered design methodology	4
	Responsiveness	3
	Energy efficiency	3
	Remote control of smart features	3
Responsiveness	Automated	7
	Occupant centered design methodology	6
	Real-time monitoring	6
	Energy efficiency	5
	Advanced technology	3
	Sustainability	3
	Learning ability and prediction of occupant preferences	3

As a result, it was interesting to note that both definitions and features given by the participants have changed according to their nationality and experience of place basically due to the cultural norms and behavioral preferences. For instance, in the European countries, where the net-zero energy buildings are favorable due to the directive of "Energy Performance of Buildings Directive" published in 2010, utilization of low technology and more consideration on passive approaches are mentioned more frequently. On the other hand, the participants from USA give more attention to the advanced management and control systems.

The second question was related with the features considered in the construction industry to design and build an intelligent office building in practice according to the participants' practical experience. With this question, the intention was not to ask the experts how intelligence can be achieved; rather, the question was related to how intelligence can be addressed and embedded into the design.

One of the experts stated that an office building is denoted as intelligent if it has the following features are:

- *"building automation system with advanced monitoring and control systems,*
- *enhanced digital operation and maintenance management systems having preventive maintenance plans and schedules, predictive maintenance capabilities,*
- *demand-controlled systems (outdoor air, lighting, lifts&elevators, water fixtures, etc.)*
- *advanced digital monitoring and performance management systems (energy efficiency and water use targets and benchmarking, waste, carbon emissions, etc.)*
- *recovery and generation of energy with renewable resources,*
- *diversion, reuse, recycle infrastructure of waste,*
- *advanced administration management systems (CCTV, keycard systems, lift & elevator traffic management, etc.)*

- *connectivity and adaptation to sustainable and resilient city practices and regulations,*
- *advanced monitoring and response system infrastructure resilient to natural disaster risks (flood, earthquake, etc.)"*

Another expert listed the main features of IOB:

"Systems are connected - The most fundamental feature of a smart building is that the core systems within it are linked. So, water meters, pumps, fire alarms, power, lighting etc. are all connected. This is what makes a building "smart" – the ability of the systems within it to talk to one another.
The use of sensors - Sensors are an integral part of smart buildings and play an important role in collecting data to inform decisions about where to allocate resources. So, for example, footfall counters may be integrated into the building to provide information on where people are at certain times of the day and which areas are high traffic.
Automation - Information is gathered and analyzed by the systems that have been put in place in a smart building – importantly, this is done constantly and in real time. This ongoing monitoring allows for automated adjustments that can control conditions across an entire building.
Data - Smart buildings generate a large volume of valuable data about their own use, which is something that regular buildings simply don't do."

The words expressed by the experts with regards to the features where each one is accompanied by examples of applicable strategies are mainly categorized into two, design and technology being the enablers of the IBs. Some experts evaluated intelligent features as advanced building systems with use of IoT whilst others boldly highlighted the importance of passive design. Within this perspective, the responses of research participants are summarized in the following paragraphs, together with some details of their comments on what should be the IBs' characteristic. There were two focuses on the IB design: passive design and utilization of technology.

Table 5.5. The words expressed by the experts for design characteristics of the IBs

<table>
<tr><th colspan="2">DESIGN</th></tr>
<tr><td colspan="2">• Maximum possible built-in passive design
• Flexibility
• Personalized comfort</td></tr>
<tr><td><u>Internal Layout</u>
• Building Information Modeling
• Smart Architectural layouts
• Hybrid spaces (Gyms, Health, Living)
• Adaptable and flexible layouts
• Smart furniture designs
• Smart electrical provisions
• Increase plant room efficiency</td><td><u>Façade Design</u>
• Improved envelope
• Sustainable façade designs
• Operable facade elements
• Automated windows /automated shading/ automated louvers
• Self-shading / Sunlight responsive shading
• Natural ventilation
• Daylight</td></tr>
</table>

Design starts with the passive design, specifically with the statements that "first and foremost MUST be passive design, and to the maximum possible must be built-in; only when the passive design is exhaustively explored and where possible implemented, active design can be considered; this includes technology within the building footprint as well as infrastructure services"; "first of all, reduce the consumption, then design the equipment to meet the loads with less technology, such as the use of heat pump systems in combination with a good/excellent envelope." Furthermore, cost, climate context, and clients' requirements are highlighted as one of the design considerations, and the early-stage simulation software to reflect very realistic scenarios was given as a suggestion. It was indicated that those who considered the IB design as climate-responsive listed the features of natural ventilation, passive design, and improved envelope (Table 5.5). Furthermore, the responses are given below obviously prove the importance of design by mentioning the sustainability aspect:

> *"It can be a green building. Energy, water, waste, and policies should be under control in an intelligent office. Using renewable or sustainable*

materials, reducing energy consumption or using renewable energy, using water harvesting and purification systems, enhancing indoor air quality, maximizing natural light etc., can be some features of intelligent offices."

"The construction industry offers components which can be helpful for the integrated design. Often in my 30 years as a consultant, we develop new components as key elements of the concept realization and prove with simulations which later became a standard, like the decentralized ventilation systems or thermal activation of concrete structures."

"This is an environmental and energy question: a carbon question. For us, using good insulation, external shading and building configuration to reduce energy demand and to build in a way that reduces carbon emissions. To use the most efficient-optimized devices and systems of providing energy, including geo thermal, solar and wind. In our case, we are also focused on buildings of engineered timber as a way of reducing carbon emissions."

"Again, maybe I would use the term "high-performance building". In that case, the building has a well-designed facade potentially with automated + motorized external shading and a separate internal glare protection device for solar gain control, probably a heat pump to be all-electric, optimized massing, EnergyStar appliances, and some PV."

"An intelligent office building should be an adaptable structure which is then resilient to change to the natural social and economic environment at it site. Attaching a functional name to a building could limit its life and thus its sustainability. I am at present converting old offices into apartments because the market has changed. Basically, it should offer suitable workspaces to occupants which has the right comfort conditions of temperature humidity and light both natural and artificial. Workspaces need to be diverse to suit different work processes and as this cannot be known by the architect the designer must allow for the fact that the occupant becomes the agent of change. Some for instance like to work standing up

sometimes. We have not evolved to sit in front of a screen all day. Meeting spaces can be formal or informal, and so on".

"In Colombia, the closest intelligent buildings are the buildings that have an environmental certification like LEED, HQE."

"Construction features must be ergonomic and flexible to enable intelligent systems to function."

"Existing local codes are not enough to tackle the challenges of reducing the carbon footprint of our built environment".

Technology related words expressed by the research participants are listed in Table 5.6. BMS and its essential role are frequently mentioned in the responses, particularly with the advanced systems (especially security and telecom systems) to observe parameters like temperature, humidity, daylight, CO_2 concentration, and energy.

Table 5.6. The words expressed for technological IB characteristics

TECHNOLOGY
• Smart devices / High-tech • Complex controls (blind, ventilation, heating, cooling, drinking water hygiene) • Automating / Automation systems / Automated controls • IT integration • Self-learning algorithms • Energy-saving technology / Power saving techniques with occupancy sensor • Renewable energy production • Controllability, tracking, remote management • User control with cellphones • Application and use of data • Communication networks within building/being online / networks including wireless access

Table 5.6. The words expressed for technological IB characteristics (cont'd)

TECHNOLOGY	
Building Management System • Enhanced sub-metering (energy, water, etc.) • Centralized global energy command centre • Ambient monitoring for increased energy efficiency ***Service Systems*** • Security systems (CCTV, keycard management systems) • High technology lift & elevator systems, destination control lift, programmed elevators, optimized lift usage • Digital communication infrastructure (data, internet, fax, telephone, etc.) • Advanced fire and life safety systems, fire alarms • Sensored water fixtures • Parking lot management	***Heating/Cooling*** • Remote-controlled HVAC systems • Advanced HVAC control systems • HVAC systems integrated with BMS, CO2 sensors, and VAVs. • Control schedules for the boiler (domestic hot water), control schedules for the air conditioner. • Radiant heating/cooling systems ***Ventilation*** • Automatic ventilation systems • Decentral ventilation elements ***Lighting*** • Auto-controls for lighting • Advanced lighting control systems • Lighting automation systems integrated with daylight and occupancy sensors

Controllability is provided by high technology – monitor/automation with sensors – actuators, hardware, database, information/prediction, and learning ability, and often the implementation of automated and/or semi-automated systems is associated with intelligence. Further, the sensory design to measure environmental parameters appeared to be a key factor for the building intelligence in practice with IoT devices so that BAS will enable to make decisions based on the collected data. Some examples of sensory design are air conditioners and lights to turn off when human presence is not felt; HVAC and lighting systems adapting to the occupancy schedule in real-time; the "intelligent" way of controlling the erection process (with a smartphone and the computer); integration some automatic sensor for enlightening the office, when someone enters the office; use of smart doors for the office that senses humans as they appear and automatically opens; doors that can open and lock without touching keypads; remote access to electrical appliances at home (even when you are not at home). It is noteworthy that the ones who defined IB as “automated” mentioned the features to be mostly systems, IoT devices, BMS, automatic control of façade elements. One expert mentioned the feature of smart grid with the comment that intelligent offices within a smart grid may not only participate to the load shifting, increase in energy efficiency, or decrease in electricity consumption but can also contribute significantly to the reduction of CO2 emissions. The advantages of technology for buildings were expressed in the following statements:

> *“Smart buildings integrate technology and the IoT to provide solutions to the age-old issues of overspending and inefficiency in building construction and use, including: reduce energy consumption; provide building efficiency, predictive maintenance, increased productivity, and better use of resources.”*

> *“Smart buildings provide solutions, improve efficiency, reduce consumption and reduce energy costs. The use of sensors built into infrastructure and data collected in smart buildings allows for a significant improvement in the management of buildings.”*

> *“Smart Building Technology adoption is influenced by contextual issues which might consist of country, sector, firm specific barriers, and promotion strategies. Separately or mutually, these issues may foster or restrain smart building technology adoption; therefore, promoting smart building technology adoption requires awareness, better understanding of influential contextual issues, and efficient readiness to adopt.”*

5.2.2 Importance Level of the Features

Experts were asked to rank the importance of intelligent features. The data obtained from Likert scale, including neutral scores, are included in the calculation of the average score. The Statistical Package for Social Sciences (SPSS) version 25.0 was used to conduct the statistical analyses. In the statistical analysis, the numbers were assigned to each importance level as an interval scale containing intervals between the points consisting of not important (1), weakly important (2), neutral (0), essentially important (4), very important (5). Moreover, taking the elaborated points into consideration, the viewpoints of experts groups as per their demographic information such as expertise, nationality are evaluated with use of both parametric (ANOVA) for each feature (likert-type item) and only parametric approach (ANOVA) for Likert (summated) scale, namely BMS, ADV and DM. All results are provided in the following sections.

Reliability of the scale - Firstly, Cronbach's alpha value which was developed for the measurement of internal consistency of a scale was estimated (Brown, 2011; Cronbach, 1951). The point is that internal consistency reliability indicates how the items in a measurement instrument are consistent in its subscale and also within overall instrument by considering in terms of a number of items, items interrelatedness and dimensionality (Tavakol and Dennick, 2011). The overall Cronbach alpha value of this survey instrument is 0.855 considered as very good according to (DeVellis, 2003). Moreover, as indicated in Table 5.7, the Cronbach's alpha value should also be calculated for subscales, and the data analysis must be done using those summated scales or subscales instead of using individual items (Gliem and Gliem, 2003; Harpe, 2015). The acceptable value of the alpha provided in different studies ranged from 0.7 to 0.95 (Bland and Altman, 1997; Tavakol and Dennick, 2011; Gliem and Gliem, 2003). The values in this survey are all above 0.70; hence, the overall instrument and subscales can be considered reliable (Cohen et al., 2011).

Table 5.7. Realibility coefficients

Features	**Number of parameters**	**Reliability Coefficient**
Building Management System	11	0.744
Advanced Technology	12	0.811
Design Management	14	0.790

From the statistical viewpoint, the distributional behavior of the data was controlled with Shapiro-Wilk test whether it is normally distributed or not. As noted previously, none of the distributions are perfectly normal (Harpe, 2015); hence, based on the results, it could be told that a certain level of normality has been achieved for Likert (summated) scale.

5.2.2.1 Building Management System (BMS)

The survey results from likert scale part, presented in terms of means and percentages in Table 5.8, show that the most associated features with IBs are the self-adaptability of systems, HVAC, lighting, and façade elements. This result is directly related with a characteristic property of the IB in relation to its behavior as being responsive. Perhaps the most interesting finding was the relative less importance (67.2%) of the real-time surveillance of occupant behavior for data collection (BMS11) feature. Occupant control for both thermal and lighting was also found to be an important part of the IBs. The collection of data to be used for the decision-making in the BMS might be collected from the outdoor weather or indoor environment sensors; however, it seems that the experts did not prefer obtaining the occupancy data from real-time observation.

5.2.2.2 Advanced Technology (ADV)

Table 5.9 shows the results by identifying the top three features as availability of wireless communication network (ADV1), connection to the smart built environment (smart power grid, smart utility networks, and service providers) (ADV2), and easy access to fiber-optic network (ADV3). The features of advanced fire detection and protection system (ADV4) and level of integration (ADV5) with the same mean value were regarded as important by 81% and 85.7% of respondents, respectively. It is followed by the use of advanced systems according to the order of importance. It is interesting to note that the feature of self-learning ability for predicting future uncertainties (ADV12) is considered the least important one (68%) among the twelve features.

5.2.2.3 Design Management (DM)

The results (Table 5.10) demonstrated that reduction of cooling and heating load (DM1) comes first as a design consideration, meaning that the passive design approach is crucial. The performance of the building can be improved with its envelope design so as to reduce the energy requirement for heating, cooling, ventilation, and lighting. Therefore, the interest in the natural and passive design strategies relies on the fact that they meet the user requirements and increase energy efficiency without any technical systems installation with consequent financial and environmental implications. The feature of easy upgrade/renewal of the systems for the advancement of technology (DM11) that are seldom considered by designers is accepted with over 50%. One of the experts noted that IBs should be able to deal with temporary failures. Another expert noted that regarding the easy upgrade/renewal of systems as IBs should have no need for the upgrade but are flexible. Another one noted that almost never happened due to its short lifespan. Flexibility is nice, but mostly, it is about architectural space height regarding preparedness to demand and supply change. Long-term integrity of systems is preferred; it provides a robust solution. Over two-third (68%) of research participants agreed that place allocation to employees according to their preferences or mood (DM14) is very important, whereas 32% of them evaluated it as a not important feature for building intelligence.

Table 5.8. Views on the importance level regarding the features in Building Management System

FEATURES		MEAN	Standard Deviation	Answers (in %)			RANK
				Weak	Neutral	Strong	
Building Management System							
BMS 1	Occupant feedback about building in terms of comfort and satisfaction	4.38	0.86	6.6	0.0	93.4	1
BMS 2	Lighting System-Self-adaptive control based on real-time indoor/outdoor environmental data (daylight intensity and occupant behavior pattern/feedback)	4.35	1.06	12.7	1.6	85.7	2
BMS 3	HVAC- Self-adaptive control based on real-time indoor/outdoor environmental data (weather and occupant behavior pattern/feedback)	4.30	1.07	11.1	3.2	85.7	3
BMS 4	Degree of control by the occupants for radiant temperature and fresh air/odor	4.25	1.03	12.7	0.0	87.3	4
BMS 5	Degree of control by the occupants for the levels of artificial lighting, daylight shading, and glare	4.25	1.09	12.7	1.6	85.7	5
BMS 6	Façade System-Self-adjusting façade elements based on real-time environmental data (weather and occupant behavior pattern/feedback) with learning ability	4.11	1.25	19.0	0.0	81.0	6
BMS 7	Manual control of façade elements for daylight, solar gain and ventilation	4.08	1.17	19.0	1.6	79.4	7

Table 5.8. Views on the importance level regarding the features in Building Management System (continued)

FEATURES		MEAN	Standard Deviation	Answers (in %)			RANK
				Weak	Neutral	Strong	
Building Management System							
BMS 8	Façade System-Pre-programmed active control of façade elements in BMS for daylight, solar gain and ventilation	4.06	1.12	17.5	1.6	81.0	8
BMS 9	HVAC -Pre-programmed zoning control in Building Management System	4.00	1.19	19.0	3.2	77.8	9
BMS 10	Lighting System-Pre-scheduled zoning control in Building Management System	3.84	1.25	23.8	4.8	71.4	10
BMS 11	Real-time surveillance of occupant behavior for data collection	3.56	1.37	31.1	1.6	67.2	11

Note: Calculations are based on a 5-point scale from ‘Not important’(weak) as (1) to ‘Very important’ (strong) as (5)

Table 5.9. Views on the importance level regarding the features in Advanced Technology

FEATURES		**MEAN**	**Standard Deviation**	**Answers (in %)**			**RANK**
				Weak	**Neutral**	**Strong**	
Advanced Technology							
ADV1	Availability of wireless communication network	4.49	0.91	6,6	3.3	90.2	1
ADV2	Connection to smart built environment (smart power grid, smart utility networks and service providers)	4.39	0.86	8,2	0.0	91.8	2
ADV3	Easy access to fiber-optic network	4.31	1.09	13,1	3.3	83.6	3
ADV4	Advanced fire detection and protection system	4.29	1.02	6,3	12.7	81.0	4
ADV5	Level of integration (e.g., integration of HVAC with fire alarm and video surveillance)	4.29	1.05	12,7	1.6	85.7	5
ADV6	Automatic fault detection ability of all systems and structural elements of the building	4.20	1.13	16,7	0.0	83.3	6
ADV7	Smarter cleaning and maintenance of the building	4.19	1.05	11,3	3.2	85.5	7
ADV8	Advanced security monitoring and access control system	4.18	1.03	8,1	11.3	80.6	8
ADV9	Remote control ability	4.07	1.12	16,4	0.0	83.6	9
ADV10	Installation of a structured wiring infrastructure network	4.03	1.09	13,1	13.1	73.8	10
ADV11	Advanced vertical transportation system	4.03	1.03	7,9	17.5	74.6	11
ADV12	Self-learning ability to predict future uncertainties	3.71	1.24	23.8	7.9	68.3	12

Note: Calculations are based on a 5-point scale from ‘Not important’(weak) as (1) to ‘Very important’ (strong) as (5)

Table 5.10. Views on the importance level regarding the features in Design Management

FEATURES		MEAN	Standard Deviation	Answers (in %)			RANK
				Weak	Neutral	Strong	
Design Management							
DM1	Reduction of heating, cooling, lighting and ventilation load	4.80	0.68	3.3	0.0	96.7	1
DM2	Preparedness of the systems to respond to the short-term (demand and supply change) and long-term (climate change) changes	4.63	0.58	1.6	0.0	98.4	2
DM3	Integrity of systems in the long term	4.57	0.73	3.2	0.0	96.8	3
DM4	Application of natural/passive design strategies instead of active systems	4.56	0.87	6.6	0.0	93.4	4
DM5	Reduction/Reuse/Recycle of water	4.47	1.08	10.0	0.0	90.0	5
DM6	Reduction/Reuse/Recycle of waste	4.43	1.07	9.8	0.0	90.2	6
DM7	Knowledge of the occupant on how the building operates	4.27	1.08	14.3	0.0	85.7	7
DM8	Installation of renewable energy systems (ex. solar, wind and geothermal)	4.25	1.09	14.8	0.0	85.2	8
DM9	Improved communication for teamwork and collaboration	4.23	0.99	8.2	4.9	86.9	9
DM10	Access to outdoor space both visual and physical	4.20	1.19	13.1	3.3	83.6	11
DM11	Easy upgrade/renewal of the systems for advancement of technology	4.19	1.06	14.3	0.0	85.7	12

Table 5.10. Views on the importance level regarding the features in Design Management (continued)

FEATURES		MEAN	Standard Deviation	Answers (in %)			RANK
				Weak	Neutral	Strong	
Design Management							
DM12	Easy of space reconfiguration and extension for the changes in size and work practice	4.02	1.10	15,9	1.6	82.5	13
DM13	Degree of flexibility of façade elements for renovation and future changes	3.62	1.31	31.7	1.6	66.7	15
DM14	Place allocation to employees according to their preferences or mood	3.59	1.33	30.2	6.3	63.5	16

Note: Calculations are based on a 5-point scale from ‘Not important’(weak) as (1) to ‘Very important’ (strong) as (5

5.2.2.4 Comparison of Viewpoints Among the Experts

Inferential statistics indicate whether the analysis of results drawn from the sample data supports a certain hypothesis, and the conclusion may be generalized for the rest of the population. Thus, the one-way analysis of variance (ANOVA) method was used to compare the means of results according to the responses of the groups since the number of groups is more than two according to McCrum-Gardner (2007). Then, Tukey's test for pairwise comparisons was made to determine statistical differences. The expert's view on the level of each feature's importance measured by the five-point likert scale in the survey was compared according to the groups formed in terms of their expertise (consultant, designer, researcher, and others), years of experience (0-3 years, 3-5 year, 5-10 years and more than 10 years), nationality (Asian, American, European and African) and place of experience (Europe, Asia, Africa, America and worldwide) in the built environment. Each feature was analyzed by one-way ANOVA followed by a post-hoc test (Tukey's test). The alpha value in the post hoc test was set as 0.05, corresponding to a significance level of 95 %. The null hypothesis is that the means of the groups are not significantly different.

The comparison among the groups in terms of their expertise indicated that their perceptions were statistically significant. Designers perceived the features of advanced fire detection and protection system (ADV4) ($F=3.381$, $p=0.024<0.05$) and advanced vertical transportation system (ADV11) ($F=3.136$, $p=0.032<0.05$) more important than the consultants. Furthermore, the researchers gave more importance to the feature of self-learning ability for the prediction of future uncertainties(ADV12) ($F=3.771$, $p=0.015<0.05$) than the rest of the group members. Lastly, the viewpoints of the consultants differ from the researchers for HVAC pre-programmed zoning control in BMS (BMS9) ($F=2.702$, $p=0.054<0.05$).

The group according to the nationality was also revealed that the null hypothesis is rejected; the experts from different nationalities consider differently. Asian and African experts give more value to the features of advanced fire detection and protection system (ADV4) ($F =4.421$, $p=0.007<0.05$) and self-learning ability for the prediction of future uncertainties (ADV12) ($F = 4.837$, $p=0.004<0.05$) than European experts. However, it is important to point out that the sample size of African experts is not enough in order to represent the population being targeted. For the features of smarter cleaning and maintenance of the building (ADV7) ($F = 3.393$, $p=0.024<0.05$) and installation of a structured wiring infrastructure network (ADV10) Asian experts think that their level of importance is higher compared to the view of European experts and the views of European and American experts, respectively. It was interesting to find out that European experts evaluated the feature of installation of renewable energy systems (DM8) more important for the building intelligence than American experts ($F = 3{,}803$, $p=0.015<0.05$).

Among the groups categorized based on the years of experience and also the place of experience, the data analysis with ANOVA method for all features did not result in the rejection of the null hypothesis at a 95% level of significance. Hence, it can be said that the years of experience and place of experience have no effect on the perceptions of the experts for the feature's importance.

5.2.2.5 Additional Comments of the Experts for the Survey

The responses from the part in the survey that any further comments were asked to the expert, the statements are presented without any interpretation as follows:

- *I agree with the features listed above.*
- *Flexibility and adaptability are most important.*
- *Energy is commonly the most compelling cost over the lifecycle of the building. Of the active systems installed as building services, HVAC is commonly (in the tropics, at least) the highest consumer of energy. Design priority must be positioned from this perspective. The Architect MUST agree!!*
- *Connectivity with occupant smartphone/laptop*
- *The questionnaire above covers this topic well.*

- *Green buildings tend to get very complicated, particularly when coordinating passive and active systems. CH2 building in Melbourne, for instance, needs a very expensive engineer/manager to run the building. Due to this reason, it achieves 60% saving in energy and resources, although it was designed to save 85% of energy and resources compared with its predecessor CH1building.*
- *The cost of going green (including all of the R&D costs) was 20% higher than other conventional buildings during the construction at that time, the year 2006. The payback period was reassessed after occupation from 10 years down to 7 years*
- *Connected charging station for electric vehicles so that electric vehicle owners can have real-time monitoring of charging station location, availability, the status of their own charging session, etc.*
- *Connection to the data network is one of the most important features that an IB should have.*
- *Outdoor space, protected from traffic noise and fumes, trees, plants, different ground treatments, different seating options, water and sky view is very desirable. The balcony is a must-have feature to get up from desk per a timer every 45 minutes and walk the balcony, stretch and get daylight. The entrance to a building, entrance sequence is very influential how you feel starting and ending the day. Earlier walked to my office from bus stop along a path, past cow pasture and trees. Later walked to office via a parking garage - awful!!!!*
- *Inclusion of sufficient number of charging stations for zero emission electric vehicles.*
- *Climate action in the built environment is a MUST!*
- *For the feature of "Installation of renewable energy systems (ex. solar, wind and geothermal)". This mostly depends on the site contexts and resources.*

- *I think Asia lags behind Europe and the US in building truly intelligent buildings.*
- *Location may be anywhere once office can have attributes of smartness and intelligence.*

5.2.3 Review of Intelligent Building Examples

The building design is an innovative combination of building form, high-performance technology, occupant interaction with the building, and passive design strategies. The descriptions for the IBs written in the survey by the experts are summarized within this framework. For the intelligent building examples, some of the participants classified the IB into high-tech and low-tech by providing examples for both of them. That's why the application of such terminology was further investigated with real-world applied concepts and discussed in Chapter 6. In order to highlight the conceptual ideas mentioned above and in the literature, case studies help to indicate how the word *intelligence* has been applied in terms of architecture and technology in today's world.

In the survey, the experts were asked to provide an example of IB to find out the true applications of rigorously applied concepts. Table 5.11 documents real building examples in terms of the strategies applied passively or actively for building services, (heating, cooling, ventilation, and lighting). Intelligent characteristics for façade such as individual control, motorized blinds, or automated shading are especially highlighted. Then, management-related features of how the information is collected through BMS and how the collected data is used for self-learning and communicating with the occupants are presented. Lastly, if the building generates its own energy from natural resources such as geothermal through boreholes, the information is given. The descriptions were found over the web pages and presented by specifically concentrating on their intelligent features in terms of building management systems and design concepts in a more comprehensive format, and also, the details of location and the year of completion are included. Finding out the applied intelligent features in practice is the core aim of the study; hence, the information of the buildings which are the epitome of IBs is provided without any interpretation on the IB features.

Table 5.11. The features of intelligent building examples

1	**Place: Canada** **Year: 2009**	**Manitoba Hydro Place**
		Intelligent features Source: Fortmeyer and Linn (2014)
	Building Management System	Extremely advanced building management system (25.000 sensors including weather stations on the roof tower and three-story podium roof) User can open the hopper-style windows
	Design Management	*Façade:* Dynamic Double Skin Curtain Wall Façade. *Lighting:* Dimmable lighting. *Heating & Cooling:* Radiant slabs. *Ventilation:* Displacement ventilation and also natural ventilation with solar chimney. *Building's Energy:* %60 percent energy saving compared to a conventional one. Heat and cold are obtained from geothermal wells.
2	**Place: Germany** **Year: 2019**	**Alnatura Campus**
		Intelligent features Source: Transsolar (n.d.); Haas cook zemmrich (n.d.)
	Building Management System	The aim is to keep the costs for technical systems as low as possible. Users control - opening the windows. Controllable openings in the roof of the atrium serve for ventilation. The windows are fixed shaded from the outside.
	Design Management	*Façade:* West and east façade are fully glazed; north and south façades are made of massive rammed earth material *Lighting:* Optimum natural daylight with the east and west façades are room-high glazed, and the atrium and the north-facing skylights. Artificial lighting is regulated depending on usage and daylight. *Heating:* Solar heat is used, and heat losses are minimized. *Cooling:* Cooling down the thermal mass at night by flushing. *Ventilation:* Naturally ventilated with an earth duct which preconditions the fresh air. CO_2 sensors and is supported with active fans on demand. A radiative system integrated into the space-facing sides of the rammed earth walls to be operated for wall heating and direct cooling. *Building's energy:* %100 energy-efficient. Heat and cold requirements of the building are supplied from the ground (via geothermal probes). Photovoltaic panels were installed on the roof to generate electrical energy. *Materials:* Use of recyclable and natural materials - the materials of the façade elements made of rammed earth.

Table 5.11. The features of intelligent building examples (continued)

3	Place: Holland Year: 2015	The Edge
		Intelligent features Source: Archello (n.d.); Randall (2015)
	Building Management System	The LED panels powered using the same cables that carry data for the Internet are also packed with 28,000 sensors—motion, light, temperature, humidity, infrared—creating a "digital ceiling". Occupant control for the climate and lighting at room level. The mobile application is used for finding the desk according to their needs, parking the car, adjusting the individual temperature and lighting preferences as well as informing the occupants how much energy they use. As smarter cleaning system, the people and robots clean the most used areas on that day. A typical hand drier connected to the internet lets the cleaning staff know the convenience of the bathroom for a cleanup.
Design Management		The east and west façade is 40% glass and 55% concrete for thermal mass. *Interior:* Every workspace is within 7 meters (23 feet) of a window. The relocatable walls were used by meeting very strict performance criteria. *Lighting:* 15-storey north-facing atrium and the glass facade ensure natural daylight. *Heating and Cooling:* A climate ceiling in the building that delivers both warmth and cooling. *Ventilation:* Natural ventilation (automatic openable window panels in the south façade) and mechanical ventilation (double flow heat exchanger). *Building's Energy:* heating and cooling a geothermal system located 130 metres below ground level with a connection to district heating, a PV-installation on the south façade and the roof. *Materials:* All materials used had to pass the sustainability test. *Water:* Rainwater is used for irrigation purposes as well as for toilet purposes.

Table 5.11. The features of intelligent building examples (continued)

4	**Place: USA** **Year: 2013**	**John and Frances Angelos Law Center**
		Intelligent features Source: Transsolar (n.d.); The American Institute of Architects Randall (2015)
	Building Management System	Fully automated operable windows also allow for natural ventilation.
	Design Management	*Lighting:* Natural daylight with the atrium. *Heating & Cooling*: A structurally integrated radiant cooling, which is combined with a minimal mechanical air system and provides cooling in the hot and humid summer months. *Ventilation:* Hybrid ventilation (natural during spring and fall and mechanical system during the extreme seasons). *Building's Energy:* 42 percent energy saving compared to the ASHRAE 90.1-2004 standard.
5	**Place: India** **Year: 2009**	**Kirloskar building**
		Intelligent features Source: ConstructionWeekOnline (2009)
	Building Management System	The double glazing used is a combination of operable and fixed panels.
	Design Management	*Interior:* Landscape terraces, atriums with indoor plants. *Lighting:* Maximum use of glass and provision of skylights to get benefit from natural light (90% of the offices get natural light). *Ventilation:* Water-cooled VRV air conditioning system with CO2 sensors for monitoring its levels. *Building's Energy:* Photovoltaic panels on the roof generate electricity; about 2.6% of electricity consumption. 50 % energy saving in total. *Materials:* Regional building materials, materials with high recycle content, including re-rolled steel. *Water:* Consumption reduced up to 30% and rainwater harvesting.

Table 5.11. The features of intelligent building examples (continued)

6	**Place: UK** **Year: 2017**	**Bloomberg's London office**
		Intelligent features Source: Wavre (2019); BREEAM (n.d.)
	Building Management System	Building Management System - ventilation is managed according to 60-70 integrated zonal CO_2 sensors Use of integrated ceiling panels fitted with polished aluminum 'petals' to regulate acoustics, temperature, and light as new technology. Advanced vertical transportation system.
	Design Management	*Lighting:* 500,00 LED lights, uses 40 percent less energy. *Heating & Cooling:* Fan coils integrated into the ceiling panels. *Ventilation:* Mechanical ventilation with air handling units and Natural ventilation. *Building's Energy:* Combined Heat and Power Generation system *Materials:* The facade structure is made of bronze imported from Japan. *Water:* 70 percent less water, saving rainwater, recycling the greywater.
7	**Place: Denmark** **Year: 2013**	**The UN City**
		Intelligent features Source: Arcdaily (n.d.); 3XN Architects (n.d.)
	Building Management System	A dynamic façade. The employees are able to control the sunshade from their computers. High security and accessibility standards.
	Design Management	*Interior:* Open and flexible office layout. *Lighting:* Natural light provided with the atrium. *Cooling:* Cold seawater is circulated for cooling, and so the energy consumption for cooling is eliminated *Ventilation:* Ventilated with filtered outside air. *Building's Energy:* 1,400 square meters of solar panels to generate electricity. It uses 55 percent less energy than office buildings of similar size. *Water:* Rainwater is used for toilet flushing.

Table 5.11. The features of intelligent building examples (continued)

8	**Place: Australia** **Year: 2006**	**CH2 in Melbourne**
		Intelligent features Source: Arcdaily (n.d.); the City of Melbourne (n.d.)
	BMS	No information was found.
	Design Management	*Lighting:* Maximization of natural daylight strategies. *Heating & Cooling:* An evocative undulating concrete floor structure for the building's heating and cooling - night flushing cooling. *Ventilation:* Tapered ventilation ducts on the façade. *Building's Energy:* PV system on the roof and cogeneration - 80 % energy saving in total. *Materials:* Recyclable and healthy materials are used.
9	**Place: Germany** **Year: 2002**	**German post office building (Posttower, Bonn)**
		Intelligent features Source: Transsolar (n.d.)
	Building Management System	An individually manageable heating and ventilation system and operable windows.
	Design Management	*Façade:* Completely glazed double skin with reflective solar shading. *Lighting:* Glass from floor to ceiling optimizes daylight. *Heating & Cooling:* activated slabs with the use of groundwater, local district heating system if the heating load from it is not enough. *Ventilation:* A DSF enabling natural ventilation with operable windows and decentralized supply air units integrated into the façade. *Building's Energy:* Obtained from groundwater wells fed by the Rhine River.

Table 5.11. The features of intelligent building examples (continued)

10	**Place: Austria Year: 2013**	**2226 Building**
		Intelligent features Source: Arcdaily (n.d.); Architectural Record (n.d.)
	Building Management System	Indoor environment parameters, temperature, air quality monitoring ability of occupants Building Management System (KNX BUS system) collects and records building performance data through sensors on a central facility server and controls the windows panels.
	Design Management	*Lighting:* Natural daylight. *Heating & Cooling:* Deep-set windows shaded and night cooling during the summer and, no mechanical system for heating during the winter - detailed facade a double with the of two different structural terra-cotta blocks (the inner is load bearing, the outer a special insulating block). *Ventilation:* Natural ventilation (high ceilings). *Building's Energy:* The structure maintains an average temperature of 23 degrees Celsius year-round without heating or air-conditioning systems.
11	**Place: USA Year: 2018**	**Apple Park**
		Intelligent features Source: Apple (n.d.); Fosterandpartners (n.d.)
	Building Management System	No information was found.
	Design Management	*Façade:* Glass façade *Lighting:* Increased natural daylight with full-height atria create light-filled entrance commons: social spaces that connect the park to the garden space within and glass façade. *Heating & Cooling:* Over 4,000 slabs, which span up to 15 metres (48 feet), known as 'void slabs', these multi-use elements form the structure and exposed ceiling, incorporate radiant heating and cooling and provide air return. *Ventilation:* Naturally ventilated building, projected to require no heating or air conditioning for nine months of the year. *Building's Energy:* Production of energy from renewable energy on-site (17 megawatts of rooftop solar).

Table 5.11. The features of intelligent building examples (continued)

12	**Place: England** **Year: 2012**	**The Crystal Building**
		Intelligent features Source: Arcdaily (n.d.); Siemens (2015)
	Building Management System	Building Energy Management System – information is collected from an outdoor weather station supplements over 3,500 data points within the building (Heating, air-conditioning and ventilation systems, weather station, lighting controls, ground source heat pump, solar thermal hot water system, black and rainwater systems, fire alarm and evacuation systems, photovoltaic system). Lighting is automatically adjusted.
	Design Management	*Lighting:* Natural daylight with minimum artificial light. *Heating & Cooling:* Underfloor pipes for heating and chilled beams for cooling / night flushing. *Ventilation:* Natural ventilation at moderate temperatures and mechanical ventilation. *Building's Energy:* Ground source heat pumps for heat and cold - 199 pipes with a depth of 150m. Solar photovoltaic roof panels (produces 20% of buildings' energy). No fossil fuel is consumed at the building. *Water:* Collection of rainwater and treatment of black water used for irrigation and WC flushing.
13	**Place: China** **Year: 2014**	**Glumac**
		Intelligent features Source: USGBC (n.d.); Gensler (n.d.)
	Building Management System	Advanced air purification systems reporting both outdoor and indoor air quality in real time, and a living green wall is designed to purify the air.
	Design Management	*Heating:* Radiant floor heating. *Ventilation:* Mechanical ventilation due to polluted air outside. *Building's Energy:* Rooftop PVC panels. The energy consumption reduced by 50 percent compared to ASHARE standard. *Materials:* Recycled materials were used. *Water:* 63 percent of water reduction.

Table 5.11. The features of intelligent building examples (continued)

14	Place: Germany Year: 2020	Cube Berlin
		Intelligent features Source: Arcdaily (n.d.); 3XN Architects (n.d.)
	Building Management System	Digital user interfaces via an app that enables communication with the occupant to customize and control such features as access control, indoor heating and cooling, maintenance, energy supply, room and parking reservations, charging of electric cars/bicycles, and more. Energy flow and consumption are monitored, and building operational information is stored in a server. The building learns to adjust to its users' preferences where they can control their individual preferences via app; this results in both self-learning and highly efficient building.
	Design Management	*Façade:* The double skin façade *Interior:* Enhanced flexibility in plans. *Lighting:* Natural daylight. *Heating:* Fully-glazed double façade (solar coatings on the outer skin). *Ventilation:* Natural ventilation.

The buildings, which were also highlighted as intelligent in the study of Ghaffarianhoseini et al. (2016a), named Manitoba Hydro Palace in Canada and The Edge in Amsterdam mentioned two and seven times, respectively in the questionnaire survey. The book of Fortmeyer and Linn (2014) emphasized the importance of a well-integrated environmental system of Manitoba Hydro Palace, including a façade performance, geothermal wells, natural humidification, and dimmable lighting, raised floor plenums, radiant slab, solar chimney, and an extremely advanced BMS. One expert, by contrast, stated that the BMS installed in Manitoba Hydro Palace led to managerial problems; actually, most problems have arisen from the complexity of the system.

Moreover, Alnatura Campus (10000m² gross area and 18 Million Euro as per one of the expert’s statements), Apple Campus (260.000m² gross area and 5 Billion USD as per one of the expert’s statements), and German Post Office Building- Posttower (80.000m² gross area and 78 Million Euro as per one of the expert’s statements) projects were drawn as an example of intelligence two times, whilst, only one respondent mentioned the remaining example buildings.

Comparing the buildings of The Edge and Cube Berlin with 2226 and Alnatura campus illustrated how much architecture and the level of technology integrated relates to the meaning of *intelligence* from very different approaches. The former definitely see the digitalization or application of AI as a feature, whereas the latter ones are content with using the passive design strategies as 'intelligent'.

The word 'intelligence' might be related with electronic controls. As can be seen, even though night cooling is one of the passive techniques, many of the case buildings utilize at least one computer-controlled strategy for night flushing for storing the coolth in the thermal mass with the pre-cooling purpose of the next day.

The deeper analysis from Table 5.11 reveals that the case studies helped to substantiate the following demonstrable features that could be called *intelligent*:

- Each building has a façade with variable characteristics though the used material is mostly glass. The most appealing architectural design strategies are the utilization of double-façade and the design configuration of the atrium, located mainly at the building center/core. As the first common one, the DSF minimizes the impact of extreme temperature differences of the outside climate, enabling more efficient solutions according to the climate, natural light, and solar gain with the integration of automated structural elements, louvers, and easily be modified as per the needs. The two most important functions of an atrium in multi-story buildings are the enhancement of passive solar gain advantages where the heated space facilitates natural ventilation with the stack effect and the connection of occupied spaces so the penetration of daylight into the office spaces. Further, it enables the people to see and communicate with each other.
- The active and automatic control of the façade fashion is still a favorable option to control the indoor environment conditions; however, today's intelligent buildings have also enabled individual control for their users.
- Most of the buildings aim to produce energy at the building site instead of importing from non-renewable energy sources.

- For heating and cooling systems, the “cold ceiling” system is the most common strategy because it replaces the fan-coils and distribution lines inside the building areas and related space required for those in an efficient way.
- The artificial lighting is linked with the natural daylight so that it can be dimmed according to its level of availability. The strategies such as full-height glazing or atria, light shelves were used for the enhancement of natural daylight.
- Today’s intelligent buildings use more sophisticated monitoring technologies together with sensory design.
- The solar heat is used for natural ventilation with the creation of stack-effect. In most of the buildings, natural ventilation strategies were applied. Alnatura Building can be indicated as an example; however, for the building, Glumac in China, a specific system was used to purify the air due to the outside polluted air.
- The strategies applied in the case studies indicated that the common features exist independent from where it is built, America, Europe, or East or South Asia.

As a result, the case studies across the world provide some details on the current state-of-the-art in accordance with the participants’ understanding of so-called intelligent building in real-world appliances. Moreover, it became quite clear that, eventhough the buildings could be devised in order to reduce energy consumption, the design of purely passive buildings with the aim of zero-energy building which maintains comfort during the night and day and throughout the year became more important because of environmental considerations.

5.2.4 Summary of Findings

The results reveal that all the features questioned in the survey are somehow a part of intelligent buildings; however, some are perceived more important while some are considered important at this stage of development. The respondents also mentioned a couple of expressions for the IBs as “green building,” “smart building,” or “high-performance building.” Furthermore, the features identified during the survey development process represent and cover the features depicted by the experts in the open-ended questions and observed in the IB examples. Thus, the features in the survey were validated.

Two open-ended questions answered the building intelligence from a wide perspective; hence, the sub-questions written at the beginning of this chapter have been also replied. The responses are discussed in the following chapter. The ultimate criterion of the success of IB is the good operation of the building, which is the integration of good design and technology. Moreover, the occupant's health and safety considerations with COVID 19 crisis shall draw attention to the building design.

In general, the most associated features with the IBs, which were selected as important more than 90 % by the experts, are preparedness of the systems to respond to the short-term (demand and supply change) and long-term (climate change) changes (DM2-98.4%), the integrity of systems in the long term (DM3-96.8%), reduction of heating, cooling, lighting and ventilation load (DM1-96.7%), occupant feedback about building in terms of comfort and satisfaction (BMS1-93.4%), application of natural/passive design strategies instead of active systems (DM4-93.4%), connection to the smart built environment (smart power grid, smart utility networks, and service providers) (ADV2-91.8%), reduction/reuse/recycle of water (DM5-90.0%), reduction/reuse/recycle of waste (DM6-90.2%) and availability wireless communication network (ADV1-90.2%).

As can be observed from the given intelligent building examples, the difficulty of meeting the requirement of occupants and achievement of energy efficiency simultaneously, the utilization of technology may seem like a potential solution. It can be said the buildings have accomplished a significant improvement in terms of energy efficiency. It is inferred that the low technology with almost no mechanical installation or high level of technology for communication or control can be regarded as an intelligent building.

Beyond these, the survey findings provide strong evidence for the statement that the buildings cannot be truly intelligent without being sustainable. The applied technologies in the IBs are the same as the sustainable buildings; for instance, DSF and the renewable energy produced from wind and solar energy types in the mentioned case studies are the same strategies applied for sustainable buildings in Korea (Tae and Shin, 2012). In summary, IBs are shown through the interpretation of IB concept from experts' views and through example buildings to figure out the meaning of intelligence.

CHAPTER 6

DISCUSSIONS ON CHARACTERISTICS OF IBs

What are the main characteristics of the IBs? In this thesis, the word "characteristics" is used to describe the behavior, whereas the term "feature" represents a possession. Therefore, the characteristics are considered as the properties which they arise as a result of features. The IBs are designed considering three main aspects, "technology," "occupant satisfaction," "energy efficiency," according to the information extracted from the literature studies. On the other hand, its design was focused on "occupant-centered design methodology," "automated," "energy efficiency," and "responsiveness," according to the results of survey results. The general framework outlined in this chapter concerns does not concern with the opposing arguments in the discussion of the IB, but rather its common understanding by building upon the conflicting issues related with the IBs both found in the literature and obtained from experts' opinions. The structure of this chapter is designed to stress four main conflicting issues through asking questions and arguing simultaneously to reach a consensus on these issues. The issues and related discussions arisen by interpreting and assessing literature are presented based on literature analysis, the experts' comments, and the features of real-world IB examples where the information was collected through the survey as the details given in Chapter 5. Finally, it is followed by a new approach to the IOB concept.

Issue 1- Passive Design with Less Technology

Issue 2- Automated and Occupant Control

Issue 3- High Technology and Low Technology

Issue 4- Sustainability Aspect

6.1 Issue 1- Passive Design with Less Technology

The design process is of crucial importance; however, its measurement is difficult. In the study of Gann et al. (2003), a design quality indicator tool was developed for design assessment in terms of (i) function (aspects of its use, access, and space), (ii) build quality (aspects of its performance, engineering system, and construction) and (iii) impact encompasses (aspects of its contribution to building form and materials, internal environment, urban and social integration, identity and character). Since the IBs are considered as "electronically enhanced buildings," research and development focus on increasing the intelligence of building systems instead of designing the building in an intelligent form (Kroner, 1997). One of the experts who attended the questionnaire survey pointed out that the building design should be intelligent, not the building itself. So-called intelligent design was evaluated as a prerequisite (Wigginton and Harris, 2002). The criticism in the literature should be noted: ***"We** have in fact disconnected architecture from the intelligence of the systems and the inhabitant to the point where there is a little interaction between three"* (Kroner, 1997). Thus, the integration of energy efficiency technologies into the architectural concept was revealed as an important feature of all buildings upon monitoring mostly passively cooled office buildings (Wagner et al., 2014). Therefore, the issue of passive design approach rather than being more dependent on the technology for low-energy performance without compromising the comfort requirements of occupants was one of the critical debates about the IBs. This issue is discussed by providing the description of passive design in terms of climate-responsive design, bio-inspired design, and intelligent envelope and giving the references of opposing and supporting arguments on passive design approach and high-tech found in the literature.

First of all, taking the indigenous and vernacular architecture into consideration during the design could make a huge attribution since the primitive building examples achieved occupant comfort without incorporating of intelligent technology. Kroner (1997) defined "intelligent design" as responding to the dynamic and unpredictable nature of its occupants and being in harmony with nature as well. Further, he gave an example of the Eskimo igloo architecture pointing out vernacular architecture by taking advantage of shape, structure, and internal layout as a sign of a high level of intelligence without any utilization of intelligent technologies. With this view, a number of authors suggested that vernacular architecture can be used for intelligence (Kroner, 1997; Wyckmans A., 2005; Clements-Croome, 2011). Moreover, due to the reasons of varying climate, social systems, management styles, space allocation to people, and work progress, differentiation of design concepts and built form of IBs can be observed in different regions of the world (Preiser and Schramm, 2002). The significance of climate factors which are intensity and periodicity of heat and light, precipitation and relative humidity, as well as wind or the periodicity and duration of the seasons, was pointed out since plants have unique strategies for dealing with the climate they exist in (López, et al., 2017). Therefore, design should be according to the climate (Hartkopf et al., 1997), and the scope of passive design in response to regional climate is termed: climatic design (Glaumann et al., 1999). For instance, climate-responsive strategies using passive building features were exemplified in a building at the University of the Sunshine Coast in Queensland by combining thermal mass for heat sink effects, with passive solar for winter heating and with cross ventilation at night for summer cooling (Clair and Hyde, 2009). In the questionnaire survey, an Asian designer commented that "*an intelligent building is the one that uses resources carefully and orients itself to the site conditions making most of what is available and blocking all undesired outside conditions."* This perspective was also evident that the design approach, namely "utilization of the natural ventilation control to reduce air-conditioning power consumption," was proposed as one of the intelligent indicators of the HVAC system by Wong et al. (2008). In addition, the strategy of "night cooling" was included as an intelligent feature in the case buildings presented by Wigginton and Harris (2002). Secondly, a good source for understanding the adaptation to the changing environmental conditions comes from nature intelligence, where numerous examples demonstrate to us how the *intelligence* exists as explained in the literature chapter, which enables the design with minimum energy consumption and easy way of adaptable living so-called “biomimicry” especially brings new creative approaches for the envelope design. Bio-inspired design is a sign of intelligence, as supported by other researchers with the expression “intelligent skin is similar to human skin” (Wigginton and Harris, 2002); “insect built architecture” (Sane et al., 2020; Gorb and Gorb, 2020) and “bio-inspired behavior” (Bien et al., 2002). For example, termite mounds indicate novel solutions for building ventilation considering the Homeostasis principles (Worall, 2011). In a similar approach, bioinspired façades have the potential to be climatic responsive and energy-efficient by regulating daylight, airflow, natural ventilation, and thermal behavior (Hosseini et al., 2019). Applying biomimicry concepts, however, in architecture is still in its infancy stage, particularly the systems dealing with function and process and the existing literature at the time mainly focused on materials and ideas rather than the implementation due to the lack of clear ecosystem-based systematic designs and shortage in corresponding design methods (Al-Obaidi et al. (2017).

The ideas presented above, “living in harmony with nature,” “biomimetic skin/design,” and “climate responsive design,” brought the idea of the passive design approach. As supported by many authors (Kroner, 1997; Ochoa and Capeluto, 2008; Clements-Croome, 2011), the passive design approach for the intelligence of buildings and its achievement is mostly related to the building envelope, i.e., intelligent façade. The excellent improved envelope has been mentioned by most of the respondents in the survey as an intelligent feature. Therefore, an intelligent building envelope should use natural forces available in the microclimate since all the energy flows between the building and the outside world begin with the building envelope in terms of heat rejection or collection, introduction of air flow, and attenuation sound. Therefore, another important design consideration in the active adaptation of the building envelope is its adaption to the particular climate, site, and building function (Wyckmans A., 2005). As set out in Chapter 2, intelligent skin may be made up of many layers to integrate the different functions and control between the internal and external environment to provide optimum comfort by adjusting itself automatically (Wigginton and Harris, 2002). The most recently applied strategy which combines the passive approach with technology is Double Skin Facade (DSF). DSF enables to change of the outside climate conditions. In the summer, solar heat gains lead to the creation of stack effect in the cavity and this warm air vented way with the openings of the façade. In the winter, the cavity between the two skins acts as a buffer zone, providing heated air to the building from the winter sun and also increasing the U-value of the envelope. In spite of its little knowledge and experience for optimal overall performance, it provides advantages of 'energy consumption reduction,' 'ventilation, airflow and thermal comfort enhancement,' 'daylighting and glare control,' 'sound insulation, noise reduction, and acoustic enhancement' and 'visual and aesthetic quality enhancement' (Ghaffarianhoseini et al., 2016b). The DSF was also applied in an office building in Turkey, enabling the application of automatic blinds and resulting in better energy efficiency according to the expression of a Turkish profession (Moghaddam, 2012). DSF performs as an unconditioned thermal zone that changes the building energy performance from heating-load dominated to cooling-load dominated as different approaches were explained in the research of Wigginton and Harris (2002). The application of DSF concept was also observed in three case IOBs (Manitoba Hydro Place, German post office building, and Cube Berlin) in the survey.

Wigginton and Harris (2002) considered "intelligence of the façade" with only the inclusion of active controls over the façade. In a similar way of thinking, inanimate objects are considered as "not intelligent" if it is not incorporated with IT technology (Cho and Fellows, 2000), and intelligence of the elements are related to the communication of activities among themselves (Vrba et al., 2014). On the other hand, in the scenario that 'active' systems or controls such as motorized shading systems, especially for the façade elements to control the environmental stimuli, such as solar intensity, are used, a considerable amount of energy is consumed. The solution to the high consumption of electrical energy of the electrically powered devices such as motors or actuators used on the façade was brought with the use of biomimetic actuators on a stadium structure which adjusts according to the amount of direct solar radiation and relative humidity by changing its shape without any operational energy need, complexity, wiring, and maintenance need of the devices (Poppinga et al., 2018). In most of the IB examples in the survey, ventilation was regulated by the intelligent control mechanism to operate the façade elements according to the environmental data in order to create favorable internal comfort conditions.

The idea of responding with the natural strategies or building form to the external variations rather than on building services is a sign of intelligence. This enables minimum use of energy of living for survival instead of using technology which increases energy consumption. For instance, the sun has great advantages for the generation of heat and electricity, and the wind direction could be used for the optimization of ventilation. In this way, the occupant has the opportunity to have a taste of fresh air, and natural daylight increases the positivity and emotional mode. This approach was supported by many researchers that the intelligence is not a collection of smart active features, (i) the right combination of active and passive features can save up 50-50% compared to a conventional situation (Ochoa and Capeluto, 2008); (ii) passive is better than active (Bordass and Leaman (1997). The evidence with a series of simulation results in the study by Tetik (2014) to indicate the effect of passive (orientation, WWR, fixed shading, improving thermal properties of the envelope, passive solar strategies, trombe wall) and active systems (sensor supported and automated windows for natural ventilation, lighting control, and shading devices) and hybrid design (both passive and active approaches) without considering the occupant behavior on building energy use illustrated that energy performance of smart buildings cannot be achieved only just technological active systems since passive strategies have a higher potential for savings. Moreover, passive design accrues the benefits of energy efficiency; high thermal mass, passive solar heat gain, and natural ventilation facilitate to help HVAC system load in terms of reducing its capacity, even its omission. With the application of passive design strategies, (e.g. high efficient building envelope), the mechanical systems can be significantly simplified (Schnieders et al., 2015). There are other researchers who do not share the same idea; instead, argue the disadvantages of the passive design approach. The sole consideration of passive design leads to the lack of user control against the benefit of energy efficiency (Ochoa and Capeluto, 2008). The occupant satisfaction has diminished in new passive buildings due to the lack of controllability over the natural ventilation (Bordass and Leaman, 1997).

The investigation of the IB examples in the survey displays a range of natural strategy applications as also the feature of application of natural/passive design strategies instead of active systems (DM4) was considered important in the survey. In general, natural ventilation was the first aim; however, a mix-mode ventilation strategy was applied for the extreme conditions. Lighting strategies include specific façade design options to redirect the daylight or reflect with shading devices, either motorized or fixed. Due to its crucial role on the energy performance of the building and occupant comfort, *intelligence* of the façade should be an integration of technology and intelligent form (passive approaches). As a holistic approach, the outer shell (the shading system for visual and thermal comfort and the level of insulation) shall carefully be designed in a unique way by taking advantage of passive strategies based on regional climate conditions to reduce the requirement of mechanical systems and consequent energy consumptions and emissions. Furthermore, atria have been included in the design, allowing passive solar gain during the winter and enhancing the natural daylight distribution. In addition to having an installed mechanical cooling system, most of the buildings have used night-time ventilation or night-time flushing for cooling purposes of the thermal mass during the night so that the next morning will require less cooling energy. Furthermore, in the IB definitions made by the experts, the “climate-based design (passive functionality)” and “low technology” are coupled six times. The comment of one expert as “*first and foremost must be passive design, and to the maximum possible must be built in. Only when passive design is exhaustively explored and where possible implemented, active design can be considered; this includes technology within the building footprint as well as infrastructure services*”. This design goal is also reinforced by the intelligent features stated in the survey as natural ventilation, daylighting, passive cooling, and self-shading. Furthermore, the feature of reduction of heating, cooling, lighting, and ventilation load (DM1) was ranked as the highest in the design management section of the questionnaire**.** In view of these contemplations, the main design concept of the building intelligence is the integration of passive design strategies into the structural elements by analyzing the microclimate conditions. In this way, the reduction in the total primary energy demand is achieved as much as possible, as indicated in the preliminary study simulation results. The final piece of evidence supporting this view that "the intelligent design should be passive with the utilization of less technology" might be illustrated in 2226 Building considered as an IB by one of the experts, where the building achieves its low-energy performance by mostly with passive approaches and no heating or air conditioning system installed. The conclusion has been drawn that *intelligence* depends more on the passive design concept by integrating the technology as a supportive.

6.2 Issue 2- Automated and Occupant Control

The work environment in the IBs should meet the occupant requirements, which cover physiological, psychological, social, and personal needs. The user was considered subservient to the technology in the 1990s (Harrison, 1992). Later, the meaning of "value of design" given by Gann et al. (2003) as the benefits that accrue to users through ideas developed in the design process and then acted on through production. The IBs bring safety, convenience, efficiency, and entertainment to people's lives in the 21st century (Luo et al., 2009). Given the review results for state of the art, de Silva (2012) mentioned the six application areas of smart homes as security, eldercare, healthcare, childcare, energy efficiency, and better life such as entertainment activities. By way of example, suppose that the building will be used by the disabled or elderly or an individual who does not like to adjust the inside temperature or prepare the coffee himself, then the automated functions are the best alternative. The level of the automation affects the degree of occupant control, and therefore, the basic question is reframed as how much the automation can interrupt or support their way of living. This is one of the questions which should be asked earlier during the design stage. In the following paragraphs, two conflicting applications, automation (pre-programmed or self-adjusting) and occupant control, are argued by explaining controllability, automation, the importance of individual control, and occupant behavior.

First of all, Powell (1990) brought the idea of responding user needs where individuals are also able to control their own environment. The perceived control to adjust the indoor environment is linked to human performance factors like productivity, health, and comfort (Bordass and Leaman, 1997). A number of studies supported this debate in relation with the effect of individual controllability on occupant satisfaction (Kroner, 1997; Wagner et al., 2014; Bordass and Leaman, 1997; Brown et al., 2009; Cole and Brown, 2009). It was proved that there is a strong correlation between the individual controllability of indoor comfort parameters such as glare protection, indoor temperature, and occupant satisfaction. Occupant satisfaction refers to the users' perception, safety, health, and well-being (Meistad, 2014). The survey results indicated the importance of occupant control for the indoor environment, HVAC system (BMS 4), and light system (BMS5). Thus, user satisfaction is a crucial and integral requirement for intelligent office buildings (Preiser and Schramm, 2002). Considering the different perceptions, the comfort conditions for the occupants could not be standardized based on only one person. Participants who attended to the survey put a great emphasis on "occupant-centered design methodology" to be the most significant aspect of the IBs. The same statement was made by Clements-Croome (2011) that if organizational performance depends on individual performance, then user-centered design principles should be applied.

Bordass and Leaman (1997) drew the attention that human management is another important aspect in securing good energy building performance, particularly for the air-conditioned buildings. The occupants should be treated as passive or active to meet their comfort requirements (Brown et al., 2009). Powell (1990) used the wording of "user intelligent building" during his discussion on the level of control to design for intelligence. During the design, architects and engineers' understanding of how the occupants and building will interact is important. In this regard, the question of how the occupant behavior affects the building performance was searched in previous studies and found that the unaware energy behavior of the occupants can increase a building's designed energy performance by one-third (Nguyen and Aiello, 2013; Shaikh et al., 2014). An earlier study by Sharples et al. (1999) proposed a new approach to the idea of building intelligence based on learning capability in building control systems from the acquired sensor data instead of pre-programmed models and behaviour-based solutions highlighted to help older and disabled people. Research by Penga et al. (2018) on learning occupants' behavior by machine learning techniques (supervised and unsupervised learning) to prevent the unnecessary energy consumption of HVAC system resulted in energy savings of between 7% and 52% compared to the conventionally-scheduled cooling systems. Further, in the investigation of energy savings based on occupancy pattern information of HVAC system and lighting control in office buildings, the simulations indicated a saving potential of up to 34 percent (Oldewurtel et al., 2013 Another study tested an improved reinforcement learning controller to obtain an optimal control strategy of blinds and lights by learning occupant preferences, thereby, integrating users in the control loop and the results indicated higher human comfort, more user acceptance and more energy saving potential (up to 10%) (Cheng et al., 2016). Nguyen and Aiello (2013) drew a conclusion from the previous studies that occupancy-based control provided up to 40% energy saving from HVAC system and the adaptation of a combination of modern control strategies, such as daylight harvesting, occupancy sensing, scheduling, and load shedding provided up to 40% energy saving from the lighting system. A recent inter-disciplinary approach by Kar et al. (2019) called ReViCEE - a Recommender-system based Visual Comfort, and Energy Efficient preference learning algorithm learns user-preferences both personalized user-level and collaborative user-level through collected historical data from sensing technologies, and then it generates recommendations using ML techniques to meet dynamic visual needs at an individual level resulting in savings up to 72% when compared to the conventional lighting systems used. Zhang et al. (2018) highlighted the outcome from the review about the occupant role on building energy performance that there exists an energy-saving potential depending on the occupant behavior, which ranges between 10%−25% for residential buildings and 5%−30% for commercial buildings. In another study, the occupants were informed on how much energy they consume; in the six-week behavior change campaign, a reduction of 7-10% in electricity and 50% in natural gas was achieved (Timm and Deal, 2016). These studies have shown that occupancy behavior patterns in relation with their usage and preferences, such as the frequency of opening windows, adjustment of indoor temperature, are more important than the use of automation to optimize building energy consumption.

Intelligence in buildings usually implies facilities management via building automation systems (BAS) (Loveday, 1997). The main functions of the BMS include the monitoring of systems, collecting both the data in relation to occupancy and weather changes from all the sensor outstations, and reporting all the information for overall strategic management of the building. In this way, it is possible to make the most appropriate decision for the control elements. The benefits of BMS accrue with the advancement of technology which brings about self-adjustment, learning ability, and remote controllability. As such, controllability is the main issue for the IBs, and thus “intelligent building monitoring and control system” was mentioned ten times in the definition of the IBs of the survey. The controllability has three components actual control (zoning of the building and environmental services), fine-tuning capability (opportunity to adjust control), and speed of response to demands (rapid response) (Bordass and Leaman, 1997). The control systems in order to perform functions are classified as manual or automatic, and as reactive or anticipatory; where (i) automatic reactive control includes feedback proportional and integral control; (ii) automatic anticipatory control includes time switches and optimizers to prepare the system for operation in advance; (iii) manual anticipatory control includes opening a window for night cooling or changing the programme of the controller; and (iv) manual reactive control includes light switches, window blinds or opening windows (Clements-Croome, 1997). The “automation” was the first definitive word of intelligence in the literature. It was also mentioned nineteen times as being the second-highest rank in the IB definitions given by the experts in the survey. The roots of the IBs are in automation, starting from the period of industrialism (Himanen, 2003). Autonomy is one of the system intelligence attributes that have the ability of self-calibration, self-diagnostics, fault tolerance, and self- tuning, meaning that the system works with less human intervention as much as possible (Bien et al., 2002). Wang (2010) provided a system-based definition of IBs where there exist three automatic systems (3A) – building automation, communication automation, and office automation. GhaffarianHoseini et al. (2013) stated that intelligence values are related with technologies of functional automation in smart houses. Building automation refers to the deployment of various sensors, actuators, and distributed control systems to provide optimum control and automation of heating, ventilation, air conditioning (HVAC), lighting, fire prevention, and security systems in the buildings (Gunes et al., 2014). Automation in a smart environment can be viewed as a cycle of perceiving the state of the environment, reasoning about the state together with task goals and outcomes of possible actions, and acting upon the environment to change the state (Cook and Das, 2007). Furthermore, the study findings of Wong et al. (2008) revealed that IBMS should possess the capability of detecting the deviations in its operation and self-adjusting to solve the problems since three intelligence indicators for IBMS as ‘self-diagnostic of operation deviations’; ‘adaptive limiting control algorithm’; and ‘year-round time schedule performance’ are all under the attribute of ‘autonomy’. The intelligence attribute of “Adaptive limiting control algorithm” for HVAC and lighting systems was revealed as one of the important intelligent indicators according to the study results of Wong et al. (2002). On the other hand, pre-programmed-preset values, for example, the software, could control zone temperature according to the given control algorithm. According to the survey results, self-adaptive control of lighting system (BMS 2) and self-adaptive control of HVAC system (BMS3) are found more important than pre-programmed HVAC system (BMS8) and pre-scheduled lighting system (BMS10).

This result is also evident in the literature that using a predictive on/off control strategy for the office zone in a temperature model indicated less energy consumption relative to conventional on/off control (Loveday, 1997). Because self-adaptive systems are capable of dealing with continuously changing environments and occupant requirements, that provides an advantage over the things not considered or planned during the design phase. Robotics needs to adapt themselves to the changing environment very frequently and respond to unexpected events instead of having fixed behaviors (Arsénio et al., 2014); that is what is expected from the IBs. Furthermore, intelligent controllability generally applied to the façade elements also brought benefits, as proved in the earlier studies. In conventional buildings, the control of façade components is achieved manually; however, it has changed to be managed by the computerized system automatically due to saving purposes in energy consumption. In today's world, by contrast, intelligent skin being a constituent of intelligent building systems, according to Wigginton and Harris (2002) plays a critical role in controllability. Intelligent behavior of the envelope was described by Wyckmans (2005) as being adaptive to the environment by means of psychical processes of perception, reasoning, and action, which enables the envelope to solve conflicts and deal with new situations that occur in its interaction with the environment. In the same vein, Kroner (1997) highlighted the ability of IBs to sense the intensity and angle of light and solar radiation, temperature and humidity, and adjusting the building envelope for the achievement of interior performance levels. Böke et. al. (2019) added to this view that a self-adaptive system for façade records, process, and transfers the information for its adaptations. In the real IB examples, seen in the case buildings, the automation which provides the computerized programming of the building systems and façade elements enables night-time ventilation via motorized façade flaps to activate thermal storage mass with the incoming cool night air. In a review of dynamic shading and daylighting systems, the use of motorized blinds with a smart blind controller provides energy savings of a maximum 20% and 50% for cooling and lighting, respectively, compared to the static systems (Konstantoglou and Tsangrassoulis, 2016). A recent examination of the building façade's adaptability in Germany revealed that no smart materials were used; rather, automation technology has been preferred for adaptively implemented functions including solar shading, light deflection, glare protection, daylight radiation control and often centrally controlled and implemented adaptively together with ventilation and the heating and cooling functions (Böke et al., 2020).

Occupant engagement in the building control can be done through real-time occupancy data via sensors or occupant feedback collected through smartphone applications or PoEs. Chen (2010) mentioned building intelligence, acquiring and processing the collected data and information for its adaptability to lifecycle circumstance changes. The real-time monitoring through a website was investigated by the researchers (Suryadevar et al., 2015; Kelly et al., 2013). Also, IBMS provides a trend graph to illustrate real-time situations or historical data reviews (Wong et al., 2008). The real-time occupancy data collection has brought the approach of sensory design. Sensors enable the occupant to check and control the appliances and consequential energy consumption and environmental effects in real-time interactively. Kerr (2013) argued that sensory design made the buildings alive more than just providing shelter for their occupants. The second way of the collection of data is through acquiring the occupant feedback. The significance of personalized comfort was pointed out by several authors in terms of the incorporation of subjective comfort feedback (Manic et al., 2016). Informing the occupant on the design intention on how the building works and the subsequent influence of their behavior on building energy performance is one of the solutions. In this way, the occupant will learn and act accordingly. The study of Brown et al. (2009) exemplified how the effective feedback that is continual and multidirectional among the design team, operations staff, the building, and the end-users influenced their knowledge, perceptions, and adaptive behavior. They compared two green office buildings; the building, Gulf Island Operations Centre, focused on more occupant engagement than the other building (Fred Kaiser) during the design phase. Based on the conducted post-occupancy survey, overall comfort satisfaction was higher in Gulf Island Operations Centre where the occupants had more knowledge, interested in learning the building operation, and wondered whether the building performance was in line with the design intentions. In another study, the comfort feedback from the occupants on the lighting and blinds operation was collected through a q-learning based controller to minimize HVAC and lighting energy consumption without the violation of user's minimum/maximum light level constraints and the study results having collecting different user preferences (ten students and two office workers) revealed that 10% energy saving was achieved in comparison with conventional automated lighting control (Cheng et al., 2016). By gaining feedback on occupant satisfaction, POE permits tracking the performance of new high-tech systems and their effects on building occupants and the effectiveness of these systems in general (Preiser and Schramm, 2002). Occupant feedback about building in terms of comfort and satisfaction (BMS1) was the highest-ranked feature, whereas real-time surveillance of occupant behavior for data collection (BMS11) was ranked the least important in the BMS section of the survey. This indicates that the collection of occupant feedback was evaluated as a more reasonable option. The learning of occupant behavior by the BMS from the real-time data and feedback collected could be a beneficial strategy to apply. In this way, adaptive and predictive systems can solve the problems encountered due to occupant behavior and take their own action automatically.

Reconciling individual occupant control and automation might be one of the most critical tasks of the IBs, also considering the efficient management of energy use. After the investigation of the existing studies summarized in the previous paragraphs, it became evident that occupant behaviour has a big impact on building energy consumption. However, the occupants' behavior and preferences have been neglected in the operation of current building automation systems (Lilis et al., 2017). Furthermore, Buckman et al. (2014) criticized an issue with the design because it is generally assumed that the occupants will use the building based on its design; on the other hand, automated buildings are designed according to theoretical climatic conditions, occupancy, and use. A suggestion for this problem was given by Kroner (1997) that occupant representatives must be present at the beginning of the design process so that they will understand how the building works and get the maximum benefit from it. D'Oca et al. (2018) stated that occupants should understand both the design and operation of the building and provide feedback according to their personal comfort. Another solution is the enhancement of the communication between the occupant and the IB. The connection between people and their environment created by the systems increased the effectiveness of today's IBs (Ghaffarianhoseini, 2016). Nowadays, the AmI environment of the building enables the occupants to control and interact with the environment in natural (voice, gestures) and personalized way (preferences, context) (Dounis, 2010). This could be one of the communication ways with the building occupant, and this allows all types of users to not only improve efficiency and reduce operating expenditures but also create opportunities for a unique interaction between buildings and their users. The transfer of information both among the users and building started to affect occupant satisfaction. For example, in case of availability of relevant alternatives, the envelope can invite the occupant to choose among those alternatives if they are interested (Wyckmans, 2005).

De Paola et al. (2019) claimed that the intelligent systems operated based on real data could satisfy the occupant more than the manually controlled one and achieve high energy efficiency, as proved in some studies. On the other hand, the user satisfaction questionnaires for automatically controlled blinds that adapted itself to the sunlight indicated that the users are quickly getting angry at the automatic system when it does not take into account their wishes for the long-term (more than one hour) since the automatic system adapts itself mostly for the energy efficiency (Guillemin and Morel, 2001). Moreover, in the investigation of the interaction between energy-efficient office buildings and users with post-occupancy surveys, Meistad (2014) found out that automated systems limiting individual adjustment opportunities caused more complaints. Therefore, the integration of the user is an integral part of the dynamic behaviour of the system (Kolokotsa et al., 2011); whilst automation has been "de facto" standard for the IB, it should always allow for flexibility in relation to the way occupants want "to live their life" in the building

(Ghaffarianhoseini et al., 2016a). Since the motivations to design and develop the smart home are: independent living, enhancing comfort, efficient use of electricity, and safety and security (Ghayvat et al., 2015), the IBs should not be designed to operate autonomously. In the same vein, Buckman et al. (2014) pointed out the importance of balance between the allowance of occupant control and the comfortable conditions with minimum energy consumption with also the statement that the information should be provided to the occupants for their adaptation to the building. Similar to the literature, the comments of experts in the survey, there are a number of conflicting views on automation. One expert stated that automation is often associated with intelligence, while another criticized the discussion for focusing on maximum automation. Evidence for the support of this perspective can also be found in the open-ended comments; one respondent stated that "f*irst and foremost, an intelligent building should ideally encourage (and create) intelligent users that operate and occupy the building the way it was (or even better than) intended by its designers. It must, at a minimum, provide optimum daylight, natural ventilation, and connection to the outdoor environment for all occupants. Automation is absolutely required, but only in specific situations with specific purpose".* On the other hand, another expert stated that "*Avoid occupant control where possible. Occupants do not know what is best and lead to distress, confusion, and disharmony".* Therefore, eventhough the occupant control for their local environment became very significant, this could lead to some problems. For instance, closing the blinds to prevent glare shall reduce the solar gain inside, or opening the window by an occupant for getting some fresh air shall affect the indoor temperature. The thermal balance of the building might be disturbed by the occupant and resulting in inefficient energy management of the building. In this regard, the decision of applied strategies for the façade and building systems shall be made in an integrated way to prevent those kinds of problems.

In conclusion, the second justified concern on the notion of the IB is the importance of the human dimension, questioning that whether people are happy with the intervention of building automation at some level or they want to be in charge of their surroundings. Three main findings are obtained. The first one is that the main aim of the IB is to support the occupant activities, cultural preferences, individual controllability and reduce the possible complaints related to the comfort conditions. For example, suppose the use of daylight is the common practice and more preferred one. In that case, the design should be carried out accordingly, not going only for the use of the latest technology for illumination. The IBs should provide individual controllability and let occupants who prefer to open the window or feel the sunlight despite the glare on the computer screen. The quotation from Brand's video (1994) summarized the perspective: "*The building learns from its occupants, and they learn from it; main architecture is time*". Thus, the way of communication among the building and occupant with IoT-enabled technology plays a critical role such that the occupant is able to interpret when choosing an adjustment for the indoor environment quality. For example, using a visualization, i.e., high/low or coloring in the user interface application, would enable to convey the information to the user easily rather than using a technical representation, i.e., energy consumption in kWh. The automation of manual controls such as opening a window or closing the shading by the centralized computer control with the sensors and actuators might seem to be the key to resource efficiency. However, the studies proved that communication with the occupants for their adaptable behavior to the design intentions is the key. They should be informed about how the building works according to the design intention for energy efficiency. For instance, in Edge Building, a smart application has been used to collect occupant preferences, producing real-time data. This perspective was also highlighted in the survey responses that it's all about "motivating the people." This has extended the IB concept. Since always being monitored is a violation of privacy, a survey among the employees was carried out, and some of them did not agree with sharing their personnel information. Nevertheless, the enhancement of the communication between an IB and its occupants shall create a synergy that is a part of intelligent control. Secondly, the intelligent façade elements should be designed to respond to the local climate parameters by collecting or rejecting the solar heat and the daylight. The façade operations are controlled by the BMS, as seen in IB examples in the survey. To enable the operation of those elements on the outer shell of the façade, such as shading, louvers, and windows, and arrangement of other systems, i.e., HVAC and lighting systems should be planned accordingly from the very beginning of the project. Thirdly, optimizing other systems (i.e., HVAC, lighting) autonomously for the application of best long-term strategies depending on the occupant preferences is significant for the IBs. Real-time user data allowed the emergence of new building services, such as the ability to adjust the internal environment settings according to occupant preferences in an energy-efficient way. Thus, instead of only using a pre-preprogrammed schedule for the systems, with the advancement of ICT, more dynamic priorities such as occupancy and instant outside weather conditions are being used for the decisions taken in the BMS to reduce further the consumption of energy and to adjust comfort parameters in the living space. In short, the main focus of intelligent control should be on occupant satisfaction by creating a balance between occupant individual control and automation (primarily for façade control) so that energy use shall be managed more efficiently.

6.3 Issue 3- High Technology and Low Technology

Another concern in the discussion of IBs definition is the high technology concept because the last decade has been viewed through the advancement of technologies (Böke et al., 2019), particularly in information and communication technology (Cho and Fellows, 2000). Two problems are highlighted by Ghaffarianhoseini et al. (2016a) in relation with IBs of today, being affected by the "tech push and market pull" scenario, high costs of intelligent systems, and the lack of widespread expertise for monitoring their operations. An Asian architect commented that "*I think the construction industry regards the use of advanced systems as intelligent*" in the survey. In addition, the intelligence of buildings was measured and labeled as "low-tech" or "high-tech" by Harrison et al. (2012). Because technology has changed how buildings are designed, and the buildings have given a direction to the technology advancement. Therefore, in this section, the dilemma of how much technology intrusion is considered beneficial and whether the IB should represent the emerging technology or not are discussed.

The idea of IB is closely linked with the advancement of technology. The IBs recognize and reflect the technological advancements (Sinopoli, 2010). A probable stereotype of an intelligent building is that it is a possession of technologically advanced countries (Kua and Lee, 2002). Early attempts at defining intelligent building mostly highlighted technology, and Corbusier (1970) defined the house as "a machine for living in." Later, the very first IB definition was derived from "the building think for themselves" in 1984 (Sinopoli, 2010). Embedded smart devices are able to predict, recognize and control the movement and activities of users and automatically respond according to that occasion (GhaffarianHoseini et al., 2013). Therefore, building intelligence started to be related with the collection and analysis of data and act collectively together with the previous experience, like humans who are able to simulate the possible outcomes with the collected information. For example, the most common application is that the artificial lighting system is able to deactivate or dim itself automatically in response to the natural daylight levels. Most of the literature studies regarding the adaptive techniques for generating a new solution for any changes in building dynamics have focused on computational studies (cyber-physical, AI, and machine learning). Luo et al. (2009) developed a multi sensor-based intelligent security robot that finds out the fire source using the fire detection system. This robot detects the intruder and then transmits the message of the detection result to the user using a GSM modem in the event of a fire or intruder, and a client computer through the internet. Silva et al. (2012) proposed a procedure for modeling intelligent building control systems with the consideration of both their functions in normal operation and in the event of faults and thereby how to manage their consequences. However, the works on the use of AI in building systems for auto-adjustment of systems, Kolokotsa et al. (2011) argued that adaptive, neural network, and fuzzy systems did not indicate a significant improvement due to very poor transient performance in the face of abrupt changes of weather or occupant-behavior.

Another bigger concept is smart cities under development (EU mySMARTlife Consortium, 2021) and so not achieved fully at the moment. The approach for the integration of the IB with the smart city concept was discussed in the study of Lilis et al. (2017) and concluded that no future smart cities could be imagined without intelligent buildings. In the same vein, smart buildings are needed to fulfill the smart grid vision and smart city concepts (Gunes et al., 2017). The advancement in the area of information technology also brings the need for infrastructure such as the smart grid. The evolvement of the electricity grid towards a decentralized architecture due to the unbundling of the energy supply chain, the technological advancements of renewable energy sources, and political support for renewable energy use led to the bidirectional energy flows in the electricity networks (Schmidta and Åhlund, 2018). The buildings are 'plugged' into the cities' infrastructure of technology and services (Kroner, 1997). The IoT constitutes an opportunity to make smart cities with smart people and smart economies a reality; therefore, future IBs will become an integral part of the smart city concept. However, the connection to the city infrastructure might bring another complexity since the city performance in terms of its communication infrastructure reliability is also an important factor in the IB concept. The features of connection to the smart built environment (smart power grid, smart utility networks and service providers (ADV2) and easy access to fiber-optic network (ADV3) are considered quite important by the experts as being second and third-ranked in the advanced technology section of the survey.

Wang (2010) argued that IBs could not exist without the involvement of technological systems, particularly information technology (IT) within the modern building environment context. As such, AIIB Index has an indicator of high tech image, and the use of advanced technology was an indicator in the evaluation system developed by Huang (2014). Furthermore, 'building intelligence' equals to the system integration' is still under debate among the IB experts (Arkin and Paciuk, 1997). De Silva et al. (2012) highlighted the standard approach to computerize. In a similar way of thinking, the applications are generally integration of computer technology to the conventionally designed buildings in Turkey (Zağpus, 2002). Against this common understanding of IBs with high-tech images, many researchers presented their arguments. IBs can be simple or technologically sophisticated depending on the circumstances (Clements-Croome, 1997). Low-tech solutions for a sustainable approach aim at reparability (Kohler, 1999). Technologies alone do not make a building intelligent (Yang and Peng, 2001). Intelligence cannot be achieved by incorporating sensors or other systems alone (Moghaddam, 2012). The sole inclusion of high-tech and sophistically controlled services systems do not make a building intelligent (Arkin and Paciuk, 1997). The ultimate object should be focusing on simplicity (Clements-Croome, 2011). An IB does not have to include high levels of technology (Cho and Fellows, 2000). Intelligent design should not be defined simply as the use of intelligent hardware in high-tech buildings (Kroner, 1997). GhaffarianHoseini et al. (2013) highlighted the complexity and difficulty of the utilization of intelligent systems as a challenge. The integration of an increasing number of additional functions such as personalized indoor environment control, automatic cleaning of the building, and energy flow from the grid requires intensive planning and arbitration due to the complexity and interdependency among functions and systems (Jia et al., 2018). Due to complexity or lack of user operability, the realization of expected-potential benefits from intelligence may be hindered (Cho and Fellows, 2000). Chen et al. (2016) confirmed that improper operation of intelligent buildings systems leads to more energy consumption and negative economic implications. Meistad (2014) also expressed a similar conundrum that due to increased complexity, modern energy-efficient buildings are more fragile in their performance.

The technology and building systems are simply enablers to operate and construct the buildings more efficiently, to provide healthy and safe spaces for the occupants, and to enhance the market value of the building (Sinopoli, 2010). However, technology systems in the buildings, if they are not working correctly, it will not make the building intelligent (Wang, 2010). Improper operation of building intelligent systems might lead to inefficient energy use and result in benefit loss and minus Net Present Value (NPV) (Chen et al., 2016). Therefore, the consequences of a holistic sustainable approach would be the reconsideration of low-tech and low-cost solutions as opposed to high-tech short-term solutions (Kohler, 1999). Therefore, the utilization of high-tech is not necessarily the case since there are buildings constructed a long time ago that indicate smart functions. Another problem with the technology is that mechanically or electrically operated actuator technologies consume energy and are prone to system failure and obsolescence. Furthermore, Travi (2001) argued that the more sophisticated the technology, the more users become mistrustful (Travi, 2001). This brought another concern because the occupants do not have any previous experience with the new technology. The effectiveness of new technology depends on the building technology developers' way of understanding how occupants actually use their products (D'Oca et al., 2018). Hartkopf et al. (1997) argued with the statement of breaking away from high-tech conditioned space by going for fresh air architecture through the use of operable windows and doors. The end-user-oriented technologies and also flexible user-based infrastructures were suggested by Hartkopf and Loftness (1999) that instead of embedded technologies so that each occupant can reach air, temperature control, daylight and view, electric light control, privacy and working quiet, network access and ergonomic furniture. In the survey results, place allocation to employees according to their preferences or mood (DM14) was evaluated as the least important in the aspect of design management; but it was still evaluated as important.

Building intelligence is related with the collection and analysis of data and act collectively together with the previous experience, like humans who are able to simulate the possible outcomes with the collected information. AI applications and soft computing technologies such as fuzzy logic, and ANN briefly mentioned in Chapter 2 brought the feature of learning ability and ability to adjust and respond instinctively. Further then, the question of learning ability from usage patterns and using that data for the optimum response is the future feature of IBs. In a recent publication, it was highlighted that IBs should have the self-learning capability to anticipate occupants' energy-related behavior, preferences, and habits and smartly act upon them (Mofidi and Akbari, 2020). "Learning ability and prediction of occupant preferences" was also mentioned as a feature of IB in the survey responses. Further, the integration of predictive technology, i.e., weather forecasting makes the intelligent control system decide on the right operation method to keep internal comfort levels beforehand, thereby operating the optimum. With the IOT, controllability from the offsite, as noted, "remote control of smart features" in the IB definitions of the survey mentioned ten times. This feature can be observed in the case studies; for instance, smart features enabled the occupants in Edge building to adjust the building' settings, such as indoor heating and cooling, room and parking reservations, charging of electric cars/bicycles through a phone application.

Two conflicting views are found in the responses of open-ended questions that "advanced technology" was mentioned thirteen times whereas "less technology" was mentioned ten times. The survey findings indicated a clear distinction that the experts who support the use of advanced technology did not mention any low-tech solutions whilst others who support the low-tech consider technology as a reason of energy consumption for the buildings. For some of them, the IB is thought of as a place where everything can be made automatically or controlled by a computer or a phone application remotely. The "advanced technology" was expressed as 'smart technology' or 'latest technology' in the responses. Moreover, the features of availability wireless communication network (ADV1) and advanced fire detection and protection system (ADV4) were valued according to the survey results. The idea of "low technology" is noted in the form of 'low-tech,' 'the simpler the better,' 'low-tech solutions,' 'less technology' and 'working with minimum technical installations and controls.' Kolokotsa et al. (2011) pointed out that all available energy-generation and automatically and manually controlled building elements should be intelligently combined for efficient energy management. A researcher from Europe elucidated that "*all the technology used in a building should have a precise purpose; it should not be used as a budget because too much nonsense technology always ends up in little benefits for efficiency or user operation*". This statement was also underlined by three experienced professionals by saying that "*less technology in terms of MEP is more*", "*installation of only the real necessary equipment*" and "*using low-tech solutions can also make buildings very adaptable too with the additional benefits of being simple, robust and easy to understand as much as possible*." The same conclusion was drawn by Bordass and Leaman (1997) that design for manageability should be achieved by avoiding unnecessary complexity. Brand (1994) supported this idea with the statement that "the longevity of buildings is often determined by how well they can absorb new services technology." Furthermore, another expert argued that "*smart building technology adoption is influenced by contextual issues which might consist of country, sector, firm-specific barriers and promotion strategies*." The interesting finding that should be noted here is that even though, as expressed in early definitions of the IBs, the technology level was important for meeting the business objectives or organizational requirements, none of the experts in the survey mentioned the idea of business objectives.

In conclusion, one of the main justification for the dilemma of high-tech or low-tech applications is that the high level or latest technology does not make a building "intelligent". This may be well-demonstrated by including two IB examples, namely Alnatura Building where ram-earth was used as a façade material and 2226 Building where no air conditioning system was installed. Looking from the same perspective, the success of using the mud as a construction material was expressed by Heringer (2017) that it is a low-tech material; however, it gives such a high-tech performance. Kroner (1997) highlighted that the central theme in intelligent architecture is the integration of the technology with a built form so that the cultural preferences of the occupant can be met with also the incorporation to the intelligent facility management process. In the future, the advances in big data, powerful computing, and AI will change the buildings; but the IB design approach will remain the same, which should focus on simplicity and the innovative utilization of technology for a specific purpose and its complementation with the architectural concept.

6.4 Issue 4- Sustainability Aspect

The emphasis on sustainability has always been discussed in the built environment because the buildings put a big environmental burden on the earth. A building being developed within particular social and cultural contexts makes sense if it brings value to humanity. The focus of earlier IB definitions revolving around technology has shifted towards more sustainable design after 2000. Many of the concepts are pertaining to the IBs have inherent relevance in sustainable building (ALwaer and Clements-Croome, 2010). In this section, the discussion has focused on this question: how is sustainability incorporated or achieved in the IBs?

Most of the people in today's world are well aware of the energy efficiency in buildings. Because heating, cooling, ventilation, and lighting of buildings consume about 40% of the concerned nation's primary energy, IB should be used to promote ecological, economic, and social-cultural sustainability; that is, total sustainability in the built environment (Kua and Lee, 2002). Similar statements were also given by other researchers that (i) the IBs must stem from a belief in sustainability (Clements-Croome, 1997); (ii) the smartness is a part of sustainable movement (Arditi et al., 2015); (iii) emerging technologies with sustainable design maximize occupants' comfort and well-being (Ghaffarianhoseini et al.,2016a). Buildings cannot be 'sustainable' but can support sustainable patterns of living (Cole and Brown, 2009). As known, the measures for building energy efficiency and the consequent environmental effects are extensively studied and well understood in the earlier studies. The consequences of a holistic sustainable approach would be the reconsideration of low-tech and low-cost solutions as opposed to high-tech short-term solutions (Kohler, 1999). Within this perspective, to promote total sustainability in the built environment, Kua and Lee (2002) proposed to retrofit old buildings by integrating with intelligent technologies not only to extend their lifespan but also to conserve built heritage. This proposal supports the view that an important feature of all buildings was the integration of energy efficiency technologies into the architectural concept (Wagner et al., 2014). Being responsive to the changing environment with building services for occupant comfort was not enough; flexibility of structural elements and form is also necessary for the workplace's possible changes.

The significance is directed towards the adaptability by the previous researchers. Although the IBs are seen to be complex, they should be easy to operate, energy and resource-efficient, easy to maintain, upgrade, modify and recycle (Kroner, 1997). The buildings should be adaptable according to the users’ lifestyle; not the users should adapt to the building (Steward Brand, 2012). Adaptability is one of the functional requirements of office buildings (Arge, 2005). An IB must also be able to respond to individual, organizational and environmental requirements and to cope with changes (Yang and Peng, 2001). The IBs should cope with changes and be adaptable to short- and long-term human needs (Clements-Croome, 2011). Just as exemplified by Kroner (1989), dynamic enclosures should have the ability to open or close like flowers and interiors, including partitions, lighting, environmental systems, and spatial characteristics that could be rotated and moved in and out of the ground. As expressed by Glaumann et al. (2019) is that the new functions are able to be handled without major changes of the building structure. The communication infrastructures of buildings should be more intelligent and robust to accommodate these changing needs (CABA, 2008). There exist some strategies for the achievement of building flexibility in the literature. For example, the conventional method of structured cabling systems has the problems of labour and time consumption; the wireless media has the benefits of easy installation, reduced labour costs, mobility and portability, and minimum interference with occupants (Kolokotsa et al., 2011). The successful achievement of this could be illustrated as a wireless power transport system to house applications such as TV, and mobile phones were successfully in the work of Zhang (2020). The findings of the survey supported the view that the feature of the availability wireless communication network (ADV1) was considered more important than the installation of a structured wiring infrastructure network (ADV10). Further to the interior flexibility, Hartkopf et al. (1997) came up with the idea of “Lego-block” modularity concept for the creation of variable interior planning configuration. This strategy also leads the way to affordable housing for the developing countries because, in this way, the buildings could be used for multi-purposed, and the changes could be made easily. The facility manager also deals with services management, including the operation and maintenance works as well as the space management. There are a variety of computer-based building automation and control system products by different manufacturers, which makes it difficult to integrate the building services. The data communication protocol, such as Building Automation and Control Networks (BACnet) enables the integration of products made by different vendors to exchange information among these devices (Bushby, 1997), and therefore, various pieces of equipment can be linked to the underlying system via a uniform communication media (Chung et al., 2001). It is noteworthy that the design strategies for the achievement of building flexibility have no additional or little impact on initial construction cost and time; by contrast, they have higher benefits compared to the conventional design alternatives (Keymer, 2000). An expert stated that "*An intelligent office building should be an adaptable structure which is then resilient to change to the natural social and economic environment at its site"*. Supporting these statements, in the survey findings, Easy upgrade/renewal of the systems for the advancement of technology (DM11); ease of space reconfiguration and extension for the changes in size and work practice (DM12), and degree of the flexibility of façade elements for renovation and future changes (DM13) are evaluated as important by the experts.

In the IB definition responses, there was no point directed towards the cost implication resulting from the use of intelligent features. The economic dimension was not expressed directly like having a minimum lifecycle cost; however, the meaning of sustainability also covers the economic aspect of the IBs. The IB definitions provided by the experts in the survey highlighted "sustainability" eleven times. In the intelligent design process, the life –cycle of a building and its systems should be considered (Kroner, 1997). The case studies found in literature proved that life cycle energy use of buildings is higher during its operation (80–90%) than its embodied (10–20%) energy, and also normalised life cycle primary energy use of conventional residential buildings is in the range of 150–400 kWh/m2 per year and office buildings in the range of 250–550 kWh/m2 per year (Ramesh et al., 2010). Benefits of IBs are the minimization of the cost on all ongoing expenses (i.e., power, air-conditioning, environmental controls); reduction of relocation cost of individuals and services, or large group revisions and the cost possibly arising from integration problems (Flax, 1991).

The pre-design phase gives the opportunity on the sustainability performance of the building with building design considerations that will also have a continued influence throughout the building life. For the efficient management of resources, after applying passive design strategies to the envelope, the remaining energy necessary for lighting or HVAC systems is being generated on-site in general. This is also evident in the important feature of the installation of renewable energy systems (ex. solar, wind, and geothermal) (DM8) in the survey. As indicated in some built examples in survey, sun energy is utilized to generate electricity with the mounted PV on the façade or roof and use of geothermal. Having no further energy requirement from the sources outside the building is the most definitive feature of an IB, as also expressed by Wigginton and Harris (2002) that self-sufficiency is the epitomic of true intelligence. This consideration is similar to the ZEB concept, as mentioned earlier in Chapter 2. However, it is better to remind an expert's comment, "*local codes are not enough to tackle the challenges of reducing carbon footprint of our built environment*". Therefore, sustainability could be a source to change our views for the way of building design instead of being a limitation. "Smart use of resources" mentioned seven times. The features in the questionnaire, reduction/reuse/recycle of water (DM5) and reduction/reuse/recycle of waste (DM6) will contribute to the long-term goals of sustainability. In conclusion, this thesis evaluated sustainability in terms of use of resources efficiently. This might be achieved with the passive design approach as discussed earlier and with the consideration of adaptability for both structural elements and technological systems.

The findings provide evidence that the IBs should be designed and operated to support sustainable way of living.

6.5 Summary of Findings

Analyzing these participants' viewpoints together with the real world appliances and comparing them with the information repeatedly cited in the literature revealed several facts that normally challenged taken-for-granted assumptions. The findings are summarized as follows:

- The central concept of the IB evolves around the design: “intelligent design”. In today’s world, multidisciplinary teams work together on design alternatives regarding building fabric and services functioning to minimize energy consumption and to improve the building performance and productivity of the occupants. By pointing out the differences in the ways of problem-solving among engineers and scientists, it was noted that the scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things which do not yet exist (Gregory, 1966). In this perspective, the scientists try to find out what nature holds for innovative ideas and concepts, which is called the bio-mimetic design. Living nature provides clues about biomimetric applications of the buildings in terms of both architectural form and building services; hence, the design principles could be gleaned from their intelligent solutions that require low-energy. In this perspective, the results obtained from the preliminary study (Chapter 4) indicated that thermal performance of buildings depends on the envelope properties (insulation, glazing type) and orientation, geometry, and WWR that is called “climate-responsive design.” More in detail, it is related to the utilization of natural sources available at the site such as solar heat/daylight (shading, use of daylight, solar collector, PVs), air (displacement ventilation, natural ventilation, solar chimney, etc.), earth (geothermal boreholes, thermal mass, etc.) and there is also another valuable resource which is water mainly used for humidity for indoor air conditioning. This design enhances the adaptation to the environment and living with the minimum harm to nature. The challenge lies in the accomplishment of the integration between the advanced technologies (smart materials, communication devices, evolving algorithms for the optimal solution) and vernacular architectural solutions to minimize the energy consumption while creating a working environment where the occupant is satisfied while making their life easier and supporting.

- The major theme of the IBs is their connection to humanity. In line with the quotation of Gregory (1966): "the end of all design is human satisfaction", ultimate goal of the intelligent design should be to satisfy occupant needs and improve their quality of life in every dimension such as cost, health and convenience with least use of resources.

Intelligence is about looking beyond technology; it is about thinking smart and so related with the intelligent technology mostly inspired by nature and vernacular architecture where there is no possibility for mechanical system installation. Reminding us the importance that evolutionary design is healthier than visionary design (Brand, 2012).

6.6 Revisiting the Definition of IB

The key finding of the thesis is that "occupant-centered design methodology" and "energy-efficiency" are the most frequently mentioned aspects of the IB concept. Based on this, it could be said that there are two critical design aspects, enhancement of occupant satisfaction and improvement of energy efficiency to make only the building 'intelligent.' These two aspects are also important for other types of buildings. Therefore, as also stated in Chapter 2, all adjectives used for buildings "green," "sustainable," "smart," "environmentally friendly," and "intelligent" were considered the same in this thesis.

On the one hand, mechanical systems are being installed to create a good indoor environment and to meet the varying demands of occupants, and these systems consume energy. In general, to reduce this energy amount, more energy-efficient technology is installed. On the other hand, responding to human requirements could be achieved with “intelligent design.” The combination of passive design strategies, such as the utilization of thermal mass and night-time ventilation enables autonomous response with no energy consumption. Especially, the building envelope plays a significant role in determining the amount of heating and cooling load. In this way, the number of technical systems used in conventional buildings could be reduced. That’s why, the minimum amount of technology or the idea of low-tech and less-tech is a necessity for IOBs. This will automatically bring the benefits of energy-efficiency and efficient use of resources, which contribute to a sustainable way of living. The technology may be used as supportive to the passive design strategies. For example, many intelligent building examples utilized a strategy of mechanized control for night-time natural ventilation. Furthermore, the passive means gives freedom in a way that the intelligence will always be available, even when under cyber-threat or when the electricity or wireless network is gone.

Firstly, the IB concept described in this thesis is related with climate responsive design focused on natural forces (sun heat, daylight, wind, etc.), which results in minimum technical installation resulting in lower environmental impact together with the achievement of higher comfort. The passive architectural approach going way back to the history when there were no mechanical installations is evaluated as another important feature of IBs. Therefore, considering passive design strategies with their integration to the technology (active systems) is the basic design principle of the IOB concept. Secondly, the idea of IBs is rooted in intelligence which has already in nature (living with minimum energy, responding autonomously), and human thinking (perception, thinking, rationality, behavior, and figuring out) that was also explored, and relative intelligent behaviors are identified in Chapter 2. Therefore, intelligence in humans, rationality, good judgment is included in the description of the IB concept. The powerful, distinct feature of IB is “know-how”, i.e., the learning ability from what has happened and acting with the reasoning in a timely manner what will happen in the near future.

As previously stated, instead of defining the IB concept in a certain way, changing the focus to what we expect from the *intelligence* of an office building is the fundamental question because it is something living and open for enhancement. One of the key findings from the survey is that the comparison of the experts' point of views from different cultures, backgrounds, and experiences has indicated no difference. A common ground for the meaning of intelligence is possible or a framework for intelligence features of an office building could be drawn without the influence of cultural significance or designer's mindset. Even though some experts in the questionnaire survey argued that "intelligence cannot be stick to one feature" and "attaching a frozen name to a building could limit its abilities because they learn and adapt", the current understanding of the IB concept should be clarified to prevent its misuse for advertisement purposes in the building environment/market. Corbusier (1970) emphasized the importance of a clear statement by saying, "the giving of a living unity to the work, the giving it a fundamental attitude and a character." Relying on this vision, it is of crucial importance to express the fundamental character of the IOBs. Two approaches are given to describe the IOB concept:

One is to express its basic design principle:

> The core idea of the IB rooted in the occupant-oriented approach with integration of the passive design strategies with the balanced level of technology utilized only for a specific purpose in a unique way by taking advantage of regional conditions.

One is to describe its behaviors':

> The behavior of IBs is described as a) adapts and responds to its environment autonomously, b) creates a healthy and comfortable environment for its occupants, c) pursues the optimal design performance for the least consumption of energy, d) communicates with its occupants to include them into building

management process e) learns occupants' preferences to improve its performance with their feedback.

In conclusion, drawing the IB concept from all the collected information, each IB has a unique configuration of building technologies and architectural design for a particular location. The occupants are one of the most important parts of IBs; they adapt physiologically and further adapt their behaviour according to the technology installed; thus, the idea of the intelligent building design is profoundly rooted in meeting the user requirement with minimum energy. After understanding the IB concept by solving the conflicting issues based on how building intelligence was interpreted by building sector representatives, an intelligence assessment tool for office building is developed by using the importance weights of the features in the survey. The details regarding the tool concept and its usage are explained in the following chapter.

CHAPTER 7

DEVELOPMENT OF A TOOL FOR THE ASSESSMENT OF OFFICE BUILDING INTELLIGENCE

In practice, making a decision regarding building design is a complex process since it is not a quantity that can be measured by a single dimension, but rather, it is a multidimensional quantity (Bien et al., 2002). Measurement instruments, defined by Geisler (2000) as the tools used to gather the quantities reading the phenomena chosen to be measured, are being used. In this regard, the meaning of intelligence in buildings is specified according to the survey findings in this thesis. After analyzing the collected data, a tool in Excel, namely, an intelligence assessment of an office building for the pre-design phase, was created to streamline the decision-making process. Before the finalization of the proposed tool, its conceptual framework was tested to validate its workability and applicability to real buildings.

Due to the high variety of IB technologies available in the market and their integration into the passive design approach, the decision making process among the alternatives becomes difficult. Developers face dilemmas during the pre-design phase for the incorporation of intelligent features. This is critical because decisions made later on the design alternatives lead to the change of a design and relevant project management decisions resulting in the allocation of a significant amount of time and resources. Hence, by satisfying one of the thesis objectives, enabling project teams to consider what can be developed or adjusted for the building intelligence during the pre-design phase, a tool named Intelligence Assessment Tool for Office Buildings (IATOB) has been created explicitly to measure the level of intelligence in buildings. All of the intelligent features asked in the survey were rated important by the experts, and so all of them are included in terms of their importance weights in the tool. The intention was to deliver the most objective measurement possible by considering the vital aspects of building intelligence. Due to the breadth of existing technology and architectural concepts, the tendency may be the inclusion of a wide number of features; however, the IB features are generalized so that the fewer the IBs features to be evaluated, the easier this may be. To sum up, leaving the features to be included as per building regulations and legislation as a result of focus group study in the content of this tool has brought a clear understanding of intelligence and feature-based evaluation framework.

The tool provides a conceptual framework on how to create *intelligence* in buildings during the pre-design process by evaluating the features in consideration and then proposing a list of strategies where further improvements are possible. The tool could not be used as a design tool; it is a conceptual framework to cover different applications for building intelligence. IATOB tool needs a direct reference to design strategies instead of evaluating total building performance during the operation, so it will serve to guide the developers and designers in the attempts for intelligence.

In the following sections of this chapter, three main elements of IATOB are explained: (i) conceptual framework, (ii) mathematical calculations together with the analysis of survey results, and (iii) interpretation of the obtained scores with the proposed strategies for further improvement. Then, the tool validation is demonstrated, and finally, the implications from the validation process with existing building examples are drawn.

7.1 Development of the IATOB

The features asked in the questionnaire survey were put into a measurement context in a structured manner. The conceptual framework of the tool for the measurement of intelligence level focuses on three main aspects: Building Management (BM), Advanced Technology (ADV), and Design Management (DM), where a set of features for each have been drawn from the survey results. Building management involves aspects of controllability of systems and data collection for the management of building's physical environment; advanced technology encompasses aspects of building systems, connectivity with the surrounding, and design management covers the aspects of space management, architectural form, and material. With the aim to establish an aggregated evaluation, a wide range of intelligent building issues, all of the features in the survey (37 features: 11 features of BM, 12 features of ADV, 14 features of DM) were identified as important and assembled into the tool framework. As the calculations are indicated in the following section, the coefficient of correlation among the features are calculated. Accordingly, two features (DM5 and DM6) are combined into one feature as reduction of water use & waste and number of features in the tool became thirty-six. Here, it is important to remark that the features have their origin from accumulated knowledge in the journal articles as indicated in the research methodology chapter; however, it is still open for future additions or eliminations.

Figure 7.1 demonstrates a complete visualization of the tool framework in the form of a flow chart, including not only the interaction between the user and the tool; but also mathematical calculations carried out in the background. Major elements in the IATOB framework are features, weights, and proposed strategies. The decision-making process is composed of two parts:

Part 1) The assessor enters the possible score of each feature to quantify based on the nature of each feature in terms of its availability (yes/no), degree of savings in percentages (%), degree of application (easy/medium/difficult), and degree of sophistication (i.e., no control/one control/two control/three control), which reflect the characteristics of a particular building. Accordingly, the tool calculates an overall intelligence score that is a value between zero and one hundred.

Part 2) The tool provides an overall intelligence score, the scores for all aspects, and suggestions/strategies to improve the intelligence performance of the subject building.

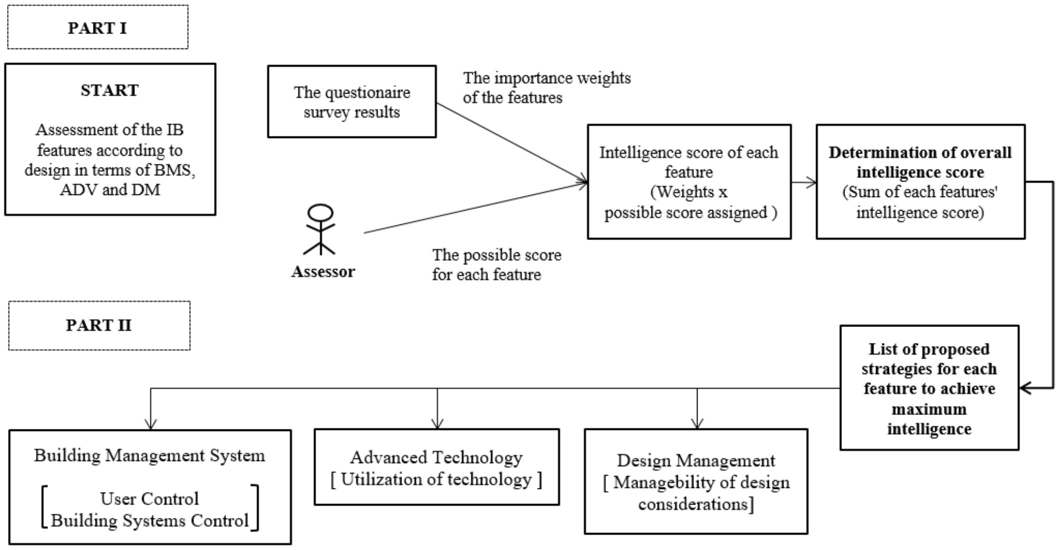

Figure 7.1. Flowchart for Intelligence Assessment Tool for Office Buildings (IATOB)

Figure 7.1 shows the structure or framework being followed in the tool; in the first part, mean values of the features representing the level of importance are obtained through the survey results; they were allocated as weights so that the significance of features was ascertained to support the intelligence. In the second part, after the allocation of possible scores by the experts, the overall intelligence score is calculated and then the strategies are addressed for the purpose of providing guidance to the design professionals. These strategies would enable the articulation of design strategies considered to allow a comprehensive understanding of design feature opportunities in terms of climate-responsiveness, technology-driven, and building management/controllability.

7.2 The IATOB

Mean weights are used to distinguish the more important features from the less important ones. For the calculation of the IATOB value, the weighted average method that is based on the features is non-interactive; hence, their weighted values can be added. Thus, before going into a deeper evaluation, the coefficient of correlation which gives the strength and direction of the relationship amongst the features with a numerical value between -1 and 1 was calculated. According to Cohen et al. (2011), a correlation ranging from 0.20 to 0.35 indicates a very slight relationship; from 0.35 to 0.65 indicates a statistically significant relationship; from 0.65 to 0.85 makes it possible to group predictions and over 0.85 indicates a close relationship. The result of Pearson Correlation coefficient calculations indicated a significant correlation between the reduction of water use (DM5) and reduction of waste (DM6) with a value of 0.717. Since these two features has a higher value for correlation, they are combined into one feature in the tool. Furthermore, the correlation coefficient between pre-programmed HVAC system (BM9) and pre-scheduled lighting system (BM10) is 0.619; self-adjusting lighting system (BM2) and self-adjusting HVAC system (BM 3) is 0.697; self-adjusting lighting system (BM2) and self-adjusting façade (BM6) is 0.688; occupant control of HVAC system (BM4) and occupant control of lighting (BM5) is 0.687; advanced fire system (ADV4) and advanced security system (ADV8) is 0.634; advanced security system (ADV8) and advanced elevation system (ADV11) is 0.613; advanced fire system (ADV4) and advanced elevation system (ADV11) is 0.664; improved communication (DM9) and easy of space configuration (DM12) is 0.640; reduction of heating and cooling loadings (DM1) and application of natural strategies (DM4) is 0.642. As can be interpreted from the values of the self-adjusting and pre-programmed HVAC and lighting systems; controllability of HVAC and lighting systems by the occupant, advanced vertical transportation, security and fire safety systems, improvement of communication with space utilization, and reduction of heating and cooling with passive approaches are found to be statistically significant. These relationships indicate that the survey participants understood the features well and filled out the questionnaire comprehensively since these features evaluate the same concept related with the self-adjustability for different building systems.

To calculate an intelligence score, a Weighted Sum Method has been used, where w_i is the importance weight corresponding to each feature i. The importance level of each features was obtained from the survey results and then the weighted calculations for each feature were performed using the formula:

$$w_i = \frac{\text{mean value of importance level for the feature i}}{\text{sum of mean values of all features}} \qquad (1)$$

The weighted feature score has an aggregated value of 1 in total, calculated by the following formula:

$$\sum_{i=1}^{n} w_i = 1 \qquad (2)$$

where, n is the total number of features.

Table 7.1. The mean values of features' importance and possible score

Intelligent Features	Mean value	Weighted score (w_i)	Possible Score (ps_i)
BM1 Occupant feedback	4.38	0.029	0 (Feature does not exist) 1 (Feature exists)
BM2 Self-adjusting lighting system	4.35	0.029	0 (Feature does not exist) 1 (Feature exists)
BM3 Self-adjusting HVAC system	4.30	0.029	0 (Feature does not exist) 1 (Feature exists)
BM4 Occupant control of HVAC system (controllability of heating, cooling, and ventilation systems)	4.25	0.028	0 (no control) 1/3 (one control) 2/3 (two controls) 1 (three controls)
BM5 Occupant control of lighting (controllability of artificial lighting, daylight, glare)	4.25	0.028	0 (no control) 1/3 (one control) 2/3 (two controls) 1 (three controls)

Table 7.1. The mean values of features' importance and possible score (continued)

Intelligent Features	**Mean value**	**Weighted score (w_i)**	**Possible Score (ps_i)**
BM6 Self-adjusting façade elements	4.11	0.027	0 (Feature does not exist) 1 (Feature exists)
BM7 Manual control of façade elements	4.08	0.027	0 (Feature does not exist) 1 (Feature exists)
BM8 Pre-programmed control façade elements	4.06	0.027	0 (Feature does not exist) 1 (Feature exists)
BM9 Pre-programmed control of HVAC system	4.00	0.027	0 (Feature does not exist) 1 (Feature exists)
BM10 Pre-scheduled lighting system	3.84	0.025	0 (Feature does not exist) 1 (Feature exists)
BM11 Real-time surveillance of occupant	3.56	0.024	0 (Feature does not exist) 1 (Feature exists)
ADV1 Wireless network	4.49	0.030	0 (Feature does not exist) 1 (Feature exists)
ADV2 Connection to smart environment	4.39	0.029	0 (Feature does not exist) 1 (Feature exists)
ADV3 Access to fiber-optic network	4.31	0.029	1 (Easy) 0.5 (Medium) 0 (Difficult)
ADV4 Advanced fire system	4.29	0.028	0 (Feature does not exist) 1 (Feature exists)
ADV5 Level of integration	4.29	0.028	0 (no integration) 1/3 (only safety codes) 2/3 (BAS-sophisticated controls) 1 (fully Integrated Building Management System)

Table 7.1. The mean values of features' importance and possible score (continued)

Intelligent Features	Mean value	Weighted score (w_i)	Possible Score (ps_i)
ADV6 Automatic fault detection ability	4.20	0.028	0 (Feature does not exist) 1 (Feature exists)
ADV7 Smarter cleaning system	4.19	0.028	0 (Feature does not exist) 1 (Feature exists)
ADV8 Advanced security system	4.18	0.028	0 (Feature does not exist) 1 (Feature exists)
ADV9 Remote controllability	4.07	0.027	0 (Feature does not exist) 1 (Feature exists)
ADV10 Structured wiring infrastructure	4.03	0.027	0 (Feature does not exist) 1 (Feature exists)
ADV11 Advanced vertical transportation system	4.03	0.027	0 (Feature does not exist) 1 (Feature exists)
ADV12 Self-learning ability for the prediction of future uncertainties	3.71	0.025	0 (Feature does not exist) 1 (Feature exists)
DM1 Reduction of heating & cooling loads (reduction in percentages achieved compared to the base building)	4.80	0.032	0% (no reduction) 25% reduction 50% reduction
DM2 Preparedness of systems for changes	4.63	0.031	1 (Easy) 0.5 (Medium) 0 (Difficult)
DM3 Integrity of systems in the long-term	4.57	0.030	0 (Feature does not exist) 1 (Feature exists)
DM4 Application of natural strategies (heating, cooling and ventilation have been achieved naturally)	4.56	0.030	0 (no natural strategy) 1/3 (one strategy) 2/3 (two strategies) 1 (three strategies)

Table 7.1. The mean values of features' importance and possible score (continued)

Intelligent Features	**Mean value**	**Weighted score (w_i)**	**Possible Score (ps_i)**
DM5 Reduction of water use & waste DM6	4.45	0.030	0% (no reduction) 25% reduction 50% reduction
DM7 Knowledge of occupants on operation	4.27	0.028	0 (Feature does not exist) 1 (Feature exists)
DM8 Installation of renewable energy (energy production in percentages achieved at site)	4.25	0.028	0% (no production) 25% production 50% production
DM9 Improved communication	4.23	0.028	0 (Feature does not exist) 1 (Feature exists)
DM10 Access to outdoor space	4.20	0.028	0 (Feature does not exist) 1 (Feature exists)
DM11 Easy upgrade of systems	4.19	0.028	1 (Easy) 0.5 (Medium) 0 (Difficult)
DM12 Ease of space configuration	4.02	0.027	1 (Easy) 0.5 (Medium) 0 (Difficult)
DM13 Degree of façade flexibility	3.62	0.024	1 (Flexible) 0.5 (Medium) 0 (Fixed)
DM14 Place allocation as per the mood	3.59	0.024	0 (Feature does not exist) 1 (Feature exists)
	$\sum$ = 150.74	**$\sum$ = 1**	

The details of numerical values for each feature are indicated in Table 7.1. The intelligence score of each feature is simply calculated by the multiplication of weights calculated according to its importance with the possible scores. Finally, an overall intelligence score, which is the summation of all features' intelligence scores in all aspects, is calculated as:

$$Overall \text{ IB Score} = \sum_{i=1}^{n} (w_i) \text{ x } (ps_i) \tag{3}$$

where n is the total number of features, w_i is the weight corresponding to each feature, and ps_i is the possible score that is acquired from the assessor as per Table 7.1.

The tool was created using MS Excel due to the fact that it is widely used and easy to understand. The IATOB excel workbook constitutes of three sheets: "Instructions" provides the explanations on how to use to tool; "Input" enables the assessor to enter information for intelligent features; "Result" to present the analyzed results together with a list of strategies to improve the intelligence and the visualization of results in the form of graph to enable easy understanding, separately for three main aspects; and "data" sheet hidden for the background calculations. In order to allow a better understanding of each feature, explanations are written and information on the level of priority indicated in the pop-up comment box.

The assessor can enter a possible score for the given features in the tool based on the nature of each feature in terms of its availability (yes/no), degree of savings in percentages, degree of application (easy/medium/difficult), and degree of sophistication (no control/one control/two control/three control). For instance, as practically illustrated in the input sheet (Figure 7.2), the assessor is able to choose one of the options for the feature of occupant controllability of lighting system (BMS5) according to the degree of system sophistication installed: "0" for no control, "1" for only for one control for the amount of artificial lighting, daylight and glare, "2" for two controls "3" for the controllability of all these parameters by the occupant.

These inputs called "possible scores" are turned into a number as 0, 1/3, 2/3 and 1, respectively as details are presented for each feature in Table 7.1. Then, these values are multiplied with the weighted score and intelligence score of each feature is calculated. Finally, all the values are summed into a value called overall intelligent score.

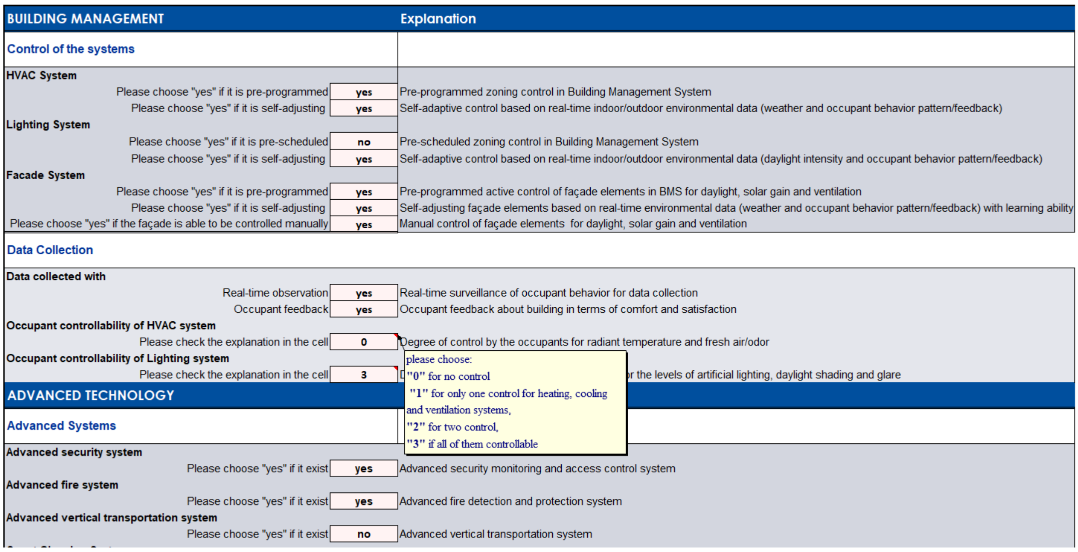

Figure 7.2. Screenshot of the user interface for the input sheet in MS Excel

In the end, the tool output shows the scores for all aspects and demonstrates where the subject building performs well as a graphical representation in comparison with the maximum achievable score and where it lacks in intelligence (Figure 7.3). For a better perception of the results, the overall intelligence score is interpreted as a qualitative scale in the "result" sheet ranging from unsatisfactory to excellent (Table 7.2), which is a similar approach to the certification assessment methods in terms of rating and labelling in the built environment.

Table 7.2. IATOB classification system

Total intelligence score	Qualitative scale
0-20	Unsatisfactory
20-40	Poor
40-60	Fair
60-80	Good
80-100	Excellent

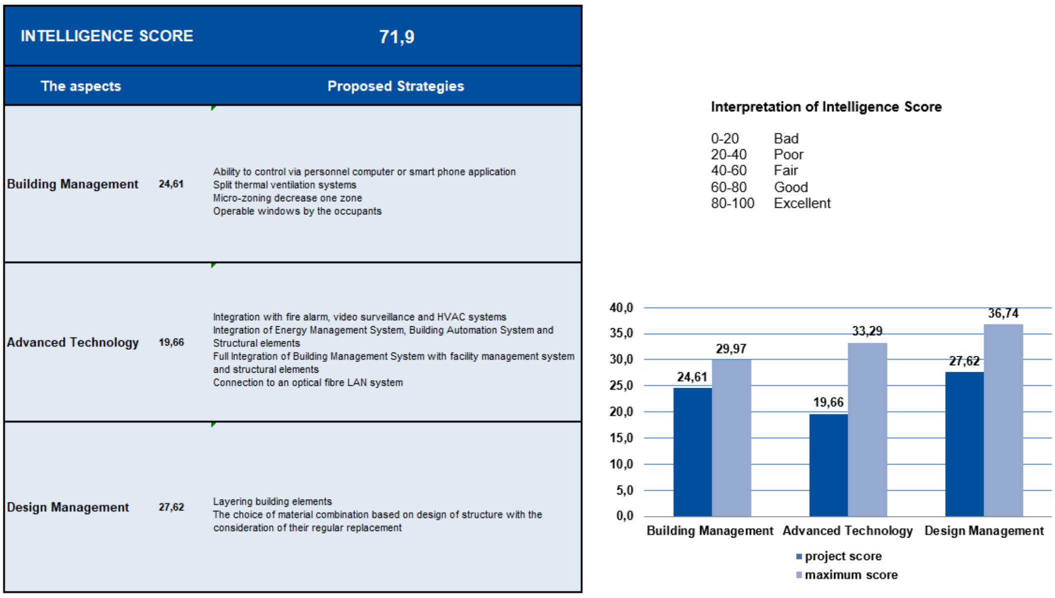

Figure 7.3. Screenshot of the user interface for the result sheet in MS Excel

The interpretation of the overall score shall not be a sole output; with a long-term aim of distributing the accumulated knowledge, the tool also suggests a set of strategies, where relatively low points are gained so that designers could feed these into the next steps of the design process. The summary of proposed strategies covering the different aspects of building design, from architectural considerations (e.g., envelope design and passive solutions) to building system considerations (e.g., HVAC systems and advanced systems selections) is given Appendix C. These strategies will help the enhancement of the integrated design approach to balance the passive design implementation and utilization of active systems as well as facility management decisions, especially considering the occupants' physical and emotional needs. The important point is that all the strategies provide a general approach having multiple options; thus, the selected option should be the one that is safe, energy-efficient, reliable, user-friendly, economical, functional, able to respond fast, easy to manage/operate, and meeting the related building legislation and commissioning requirements. The design strategies are the key for the achievement of long-term building value in terms of intelligence that gives support to sustainability. The strategies were collected as a result of a literature review and benchmarking strategies applied on the built examples provided by the research participants and applicable for both refurbishment and new construction of an office building.

The intention is to assist the building stakeholders, designers and clients with the configuration of design alternatives during the pre-design development phase. The strategies in the tool were given as a piece of advice on the general concept rather than a specific decision; thus, no unique product or technology is specified because of the differentiation of the available technologies and climate-responsive strategies amongst the countries. Furthermore, because the design criteria specific to a building project includes meeting building legislation/regulations, satisfying business needs, achieving economic and environmental targets, in addition to the responding end-user requirements and energy efficiency considerations, incorporation of an intelligent feature in one project does not necessarily represent the most appropriate option for another project. The general approach was the inclusion of suggestions for each feature which can be converted to region-based attributes and so applicable anywhere in the world. However, it should be noted that some features, such as connection to smart built environment, communication infrastructure, fiber optic system, and high-speed Local Area Network (LAN) are not a feature of a building; instead, it is a region-based controlled feature. In this regard, the features are being able to be removed according to the region-specific content factors and its necessity for the building; then, the weight of that feature are re-distributed amongst the remaining features so the total weight of features always is 100% in total. In the same vein, also if the evaluator does not have knowledge of whether that feature exists or not, it was kept out of the evaluation framework. The tool validation process was conducted by considering these situations.

7.3 Validation of the Tool

Before the final version of the IATOB, the tool was validated in terms of its applicability and reliability in two steps. The validation was done through the expert evaluations and case studies by real-life building examples, which are considered as "intelligent" by the experts who have rich knowledge and experience in the field of building design and working on developing climate responsive design strategies all over the world. The experts in the validation case study were two mechanical engineers and one architect and were well aware of the tool content because they also attended the questionnaire survey. A word document on how to use the tool and the type of information necessary for performing the validation was sent via e-mail. In the document, the experts were asked about their judgment on the strengths and weaknesses of the demonstrative examples of intelligent buildings selected by them. Then, accordingly, the prediction of an intelligence score between 0-100 was requested. Furthermore, it was requested to write down any comments/concerns that may have impacted the features, the potential drawbacks, and the tool's benefits. The document details sent to the experts for validation are found in Appendix B.

The first expert was a mechanical engineer who provided building sustainability, energy (modelling, audits, recommissioning), and commissioning services with 19 years of experience. He chose the building, namely Grander View in Canada and gave an intelligence score of 90 before using the tool classified as "excellent". During the evaluation, the feature of "advanced vertical transportation system" was kept out of the evaluation because the expert considered it unnecessary for the building and the remaining ones provided 80 points (excellent) of the required intelligent level. He found the intention of the tool very useful that it could serve as a helpful checklist during design to help ensure that key considerations like interoperability and adaptability don't get overlooked (Table 7.3). Furthermore, he stated that it could be helpful when doing recommissioning, evaluating a building portfolio, or a sale/purchase of a building.

Table 7.3. First expert's evaluation on the usage of the tool

About the building A Grander View, Kitchener, Ontario	**About its intelligence evaluation** IATOB Tool
Strengths:	**Comments on the tool:**
• Insulated concrete form (ICF) used for the exterior walls– along with good detailing around windows and doors, gives rise to an airtight envelope • Triple glazed windows for energy efficiency, and operable to offer occupant control/comfort • Dedicated outdoor air system (DOAS) • Earth tubes to temper outdoor air • Energy Recovery Ventilators • Air-source heat pumps • Mechanically assisted natural ventilation – Louvre and exhaust fan on top floor and windows on ground floor open when outdoor conditions are appropriate • High-efficiency T8 lighting controlled by daylight and occupancy sensors • The building control system was kept as simple as possible	• The tool assessed more factors than I had been considering. Also, some features aspects of a smart building are not necessarily required (e.g., Smart vertical transportation vs. simple elevator) • Recommend adding "Not applicable" or "Not Desired" to some options, such as vertical transportation. For some buildings, having "dumb" systems may be better than sophisticated "smart" controls. • The earned and lost points are reasonable.

Table 7.3. First expert's evaluation on the usage of the tool (cont'd)

About the building A Grander View, Kitchener, Ontario	**About its intelligence evaluation** IATOB Tool
Weakness:	**Evaluation of the proposed strategies:**
• Exterior shades (automatic operation and manual override) did not work well, and were not well-liked by occupants.	• Recommend adding a question to "Building Energy" or "Facility Management" categories regarding sub-metering and data logging of the building systems to allow ongoing monitoring of building performance (with energy end uses broken down by heating, cooling, heat-rejection, pumps, fans, interior lighting, exterior lighting, hot-water and equipment loads, and including domestic hot and cold water consumption) • I think the second proposed strategy is related to the flexibility of the building to allow for future expansion. This may not always be possible.

The second expert was also a mechanical engineer who is working at the green building consultancy company with 20 years of experience in this area. The selected building, he assumed the level of intelligence as 80 points which is classified as "excellent", on the other hand, the tool resulted in 67.2 points (good). The feature of "connection to the smart built environment (smart power grid, smart utility networks, and service providers)" was removed from the evaluation framework since there is no connection possibility to the city's infrastructure. Furthermore, he has commented on the scoring of installation of renewable energy systems (ex. solar, wind, and geothermal) that it should rather be in increments of 10% at max in order to be able to evaluate the buildings more fairly (Table 7.4).

Table 7.4. Second expert's evaluation on the usage of the tool

About the building A Grander View, Kitchener, Ontario	**About its intelligence evaluation** IATOB Tool
Strengths:	**Comments on the tool:**
• Passive design of the building due to solar shading, façade glass selection and building integrated PV system, efficient HVAC systems, daylighting and lighting automation, cogeneration system, building management system.	• The given features more or less cover the general framework for an intelligent building.
Weakness:	**Evaluation of the proposed strategies:**
• Lack of energy monitoring system, no demand-controlled ventilation.	• Demand-controlled ventilation may be added. Hygiene or filtering of fresh air in ventilation systems may be added, especially after Covid-19 phenomenon. • Constant monitoring of indoor air quality in terms of not only CO2 but also tVOC, ozone, particulate matters may be added due to occupant health.

The third expert was an architect with eight years of experience in building design. She considered NEST (Next Evolution in Sustainable Building Technologies) modular research and innovation building as an intelligent building with a score of 90 classified as excellent. The tool evaluated the score of building intelligence as 90.2 that is pretty close to the evaluator's prediction (Table 7.5). During the evaluation, the feature of "advanced vertical transportation system" and the features of "pre-programmed control façade elements, HVAC system, and pre-scheduled lighting system” were kept out of the evaluation framework because the evaluator thought that a self-adjusting system should be enough to get maximum points in order to be called *intelligent* and the elevator system was not necessary for a low-rise office building. In the same line of thought, she considered the features of fiber optic network and wireless network connection intelligent enough. However, she found useless the feature of structured cabling network system; however, it was included in the evaluation points of the tool. Further, she highlighted another point in the smart environment that I could see a question about if the building “donates” from its own energy harvesting further to the grid, or if its externalizing any resources, thus, again, thinking one step further and a feature outside the building.

Table 7.5. Third expert’s evaluation on the usage of the tool

About the building	**About its intelligence evaluation**
NEST (Next Evolution in Sustainable Building Technologies) modular research and innovation building	IATOB Tool
Strengths:	**Comments on the tool:**
• The building is a 1:1 scale prototype of new technologies and space typologies. Being derived from several research projects, it was designed as an open-end modular building. Here new materials, technologies, and systems are tested, researched, further developed, and validated for the construction market.	• I can see the use of such recommendations in an early stage of design. I would use this tool to evaluate a project in a pre-phase and not an existing building. • I would like to use such a tool in a pre-design phase, freeze the answers and come back to it in the construction phase after I implemented the proposed improvements. Then I would re-evaluate the project; further, I would

Table 7.5. Third expert's evaluation on the usage of the tool (cont'd)

About the building	**About its intelligence evaluation**
NEST (Next Evolution in Sustainable Building Technologies) modular research and innovation building	IATOB Tool
Strengths:	**Comments on the tool:**
• I consider the building to be an exciting example in regard to the uniqueness of the units and the synergies created between them. Despite their specific characters, for example, unit SolAce-multi functional façade for office spaces to unit Vision Wood-timber based innovations for housing or Sprint-circular construction from dismantling to re-use as fast as possible, just to name 3 of the 9 units; the conglomerate generates resources and supports all units as under one umbrella. • The project has the strength of a leading example on designing with technology and on scale-up/down strategies for flexible spacing.	• expand the tool with a construction phase or in-operation status where more detailed questions are set. • For example, maybe the project went beyond the pre-design improvements and now adopted extra features that should receive a bonus point, maybe it is only a listing of extra features. After 10 years of operation, the evaluation would need to be redone with actual numbers on the building consumption and what are their reductions. • I would include in facility management something related to transportation, if any facilities are provided like car sharing, e-mobility, charging stations etc. I consider an intelligent building one that goes beyond its singular existence; basically thinking of its users not only inside the building but also how do they get to their work place.
Weakness:	**Evaluation of the proposed strategies:**
• I consider the location of the building to be one of its biggest weaknesses -outside of the city in an industrial/office area.	• The strategies provided are valid and helpful. For my example, they are realistic to implement also after construction but I could imagine

Table 7.5. Third expert's evaluation on the usage of the tool (cont'd)

About the building	**About its intelligence evaluation**
NEST (Next Evolution in Sustainable Building Technologies) modular research and innovation building	IATOB Tool
Weakness:	**Evaluation of the proposed strategies:**
• Being far and disconnected from the urban structure of Zürich is leaving a big question mark on the integration level of such a building of technologies. Would such an intelligent building be welcomed in a city grid, what about old city centers?! Is its design site specific? Can it be applied to other city fabrics? • The scale of the building is also medium, lowrise, and I consider it fairly manageable when it comes to the exchange of energy between the units but when we think of the 10 times larger office spaces what challenges appear there?!	• other strategies that have to do with structure or façade that are not feasible later in the project; here I consider a disadvantage can accrue. • I believe that proposed strategies could change a project; I can see their strength in that regard when provided in an early design phase. They can influence the entire concept of vertical transportation or façade systems maybe even open new discussions about how spaces are configurated and the user's flow in the building. That I see as an advantage of such proposed strategies, design needs to be questioned. I also like the detailed example of what an improvement could be, it is very product specific and that gives clear directions. • Disadvantages I can only see in strategies that are too abstract. Examples of what can be done help a lot and mixing the strategies also with some open directions on where technologies might go, gives the right food for thought.

Feature-based evaluation could enhance the possibility of equal assessment of same building by different experts with different backgrounds. As can be understood from their comments and their way of evaluation, the tool is flexible for calibration according to both project requirements and regional characteristics. In short, the workability of the tool was proved with the validation results. The overall score may not reflect all the characteristics of building intelligence; however, it measures some aspects of it in a successful way.

7.4 Limitations of the Tool

As can be seen in the established framework, the weightings of features are obtained from the likert-scale questionnaire results meaning that the subjective opinion of research participants was used. Measurement instruments in the evaluation of S&T phenomena are generally accurate and precise, but tend to exhibit high bias and low sensitivity, particularly when they are predominantly qualitative (Geisler, 2000). Therefore, the experience of professionals in this area is somewhat quantified and has a very important role in the calculations. The approach resulted in a single intelligence performance score with the aggregation of the applied features. The proposed framework is unique in terms of its way of evaluation based on the availability of features and also the features that affect the environmental, economic, and social dimensions of a building, meaning that sustainability goals. The features and their weights are based on the results of the survey; hence, the knowledge and experience of the participants. However, participants with wide range of background, country, responsibility attended the survey; forming a representative sample. But still, further surveys can be performed to see if the tool is applicable to other contexts, and identify differences in the perspectives of different stakeholders from different countries.

However, the tool has some limitations; its framework was crated only for office buildings; it might be extended to other building types by keeping the original structure but adding new features specific to the building type. In consideration of these reasons, it is better to state that this tool is rather an attempt for the intelligence measurement of office buildings where more energy is consumed for the achievement of occupant comfort requirements than the creation of a concrete framework in this area. Nevertheless, the research will invoke further research and lead the way for the building assessment methodology without considering the different expressions used for the buildings, as mentioned in the introduction chapter.

7.5 Final Remarks

This study produced a user-friendly decision-making tool for the measurement of intelligence based on the incorporation of the specific features in buildings which can be very useful during the most relative phase of the project, pre-design. The tool was designed in a spreadsheet format consisting of two parts; Part I calculates the intelligence score using the weights of features defined by likert-scale measurement which gives the decision-makers a perspective and then in the Part II offers a set of beneficial strategies which guides them to design a particular building project with maximum intelligence. The tool was tested with the integration of professionals' knowledge and proved that it offers decision makers an efficient and practical approach to figure out the intelligence status of a building project during the pre-design phase.

The proposed tool was designed as a generic framework so it is adaptable to defined local context conditions (different climate context, available technology, and cultural values), and furthermore, the values of weights could be revised in the light of further research. Given the regional priorities and local area considerations, the proposed strategies could be written in more detail and also might be challenged over time with the advances in building technology. To sum up, the decision process will be simplified and conducted quickly in collaboration with the design team with the help of IATOB.

CHAPTER 8

CONCLUSIONS

The study generated a number of insights on the meaning of building intelligence and provided brief information found in the literature. The research questions raised in Chapter 2 are answered in three steps: a survey among the experts (Chapter 3 and Chapter 4), development of an intelligence measurement tool for an office building (Chapter 7), and discussion of results (Chapter 6) on the conflicting views on the idea of IBs. Chapter 8 summarizes each chapter with the presentation of findings in the following paragraphs.

In Chapter 1 (Introduction), the research area is specified together with researches questions that sought to be answered in the study. In Chapter 2 (Literature review), the existing literature was extensively studied and found out that there is no consensus on the IB concept. In the development of the survey chapter (Chapter 3), the question of IB concept is interpreted in the built environment, and the IB features were investigated through a questionnaire survey. In this way, the current knowledge of the IBs in the sector was elicited according to experts' experiences. In the preliminary study chapter (Chapter 4), it was indicated that the features in relation with the application of passive strategies are critical for the IB concept. Therefore, those features are included into the scope of the survey. In the findings chapter (Chapter 5), the survey results analyzed with statistical methods. The IB examples constructed across the world demonstrated a range of intelligent features. What constitutes of them is explained in detail together with the common properties of intelligent buildings all over the world.

In the discussion of results chapter (Chapter 6), the most widely debated areas on what an IB means are explained based on the expert's comments, survey results, and real example buildings. It was clear that the IB concept is mostly related with its design which should rely on passive design approaches to manage the resources effectively and the integration of the right amount of technology by focusing on occupant requirements.

In the tool development chapter (Chapter 7), the consensus among the industry practitioners on the importance of the criteria has reached with the survey and translated into an intelligence value with their average value. Using weighted aggregation method, features are evaluated, and one intelligence score is calculated from the tool developed by using MS Excel. For verifying the tool, three experts assessed the intelligence performance of a building. A single intelligence value was obtained by the end of the assessment, and this value was evaluated by the experts on strengths and weaknesses for the workability of the tool. In conclusion, the proposed framework helps the designers for the achievement of intelligence by fulfilling the research objective, which is the designation of intelligent features of a building and streamlines the decision-making process.

8.1 Contributions

This research made a significant contribution by addressing research questions, and the current state of the art with the case buildings and current trends are also summarized.

8.1.1 Theoretical Contributions

A new approach to the IOB concept in terms of its behavior and basic design principle given in this thesis will improve the understanding in a way that allows both interpretations according to the existing location, available technology in the region and comparison of features planned to be applied in an intelligent manner by giving a solid evaluation to help the design team. Furthermore, this study helped to promote the understanding of IB concept and resolved the conflicting views both exist among the experts and in the literature as follows:

Automated vs. individual controllability? IBs is often thought of as a building in which most of the management activities are carried out automatically. However, the occupant might be dissatisfied with the decision taken by automatic adjustment. Therefore, individual controllability should be a primary concern without affecting the design intention and scenarios for optimal building performance goals.

High technology vs. low technology? Regarding the heavy technocentricity of IBs, it is not necessarily the case to use the recent and most advanced technology, rather it is important to integrate the relevant technology into the design methodology. The innovative use of existing technology can also solve the problems in a more economical way. Rather, the important is not its simple operability for the occupants but also is its integration with the architecture. In short, intelligence is clearly one of how technologies are integrated within an overall energy or building strategy rather than the technologies themselves.

Passive design and less technology? The equal importance of passive environmental design is pointed in order to minimize the energy by using natural means, as mass, orientation, and building form, to capture sunlight, fresh air, and rainwater. The natural strategies are favorable and important in terms of energy efficiency due to the fact no mechanical equipment is installed and attributed to the economic savings and the reduction of the detrimental effect on the environment.

The role of sustainability? It is obvious that the IB is the one that responds to the natural social, and economic environment in a sustainable way.

8.1.2 Practical Contributions

The first contribution is the developed IATOB which has the flexibility in terms of included features depending on the applicable practices in different regions of the world and is so adaptable to given any cultural context. The proposed strategies would assist and guide the designer to consider a broader picture of intelligent indicators in buildings before the design or to evaluate any building's intelligence in fulfilling the user or owner expectations according to the project fund available. The second contribution is a set of recommendations where their applications may serve to improve the building conditions for occupant comfort and energy saving potential bringing the notion of IB into reality:

1. Occupant behaviour is of critical importance on building performance, better to have increase occupational awareness
2. The intelligence is not how technologies are integrated rather, it is how the architectural concept integrates with or is supported with the technology for efficient energy management while keeping the occupants satisfied with the building.
3. Low technology with the application of passive design is better than high tech.
4. The responses given by the experts in the questionnaire survey were mostly concerned with the design rather than the construction process or activities. Thus, the design phase is the most critical stage to make all decisions in relation to intelligence.
5. "Climate responsive design" is the main design strategy for minimum energy consumption by taking into the climate data. Also, energy production at the building site is important. The built examples indicated how solar energy is utilized for the generation of electricity via photovoltaic panels and how artificial lighting is used as a supplemental to natural daylighting to optimize the luminous indoor environment.

8.2 Future Research Directions

The IB concept described in this thesis represents the current situation. The concept will evolve with the technological advancements and future developments in the multi research fields such as computational sciences, smart appliances, and automated control systems in time. Therefore, the definition of the IB will remain as an open challenge.

Future research should focus on the development of more comprehensive and robust tools that measure intelligence in office buildings. There are standards for green buildings and zero-energy buildings, for instance, LEED in USA and other evaluation methods summarized in Chapter 2; however, there are no assessment methods and specific design guidelines for the IBs. The composed survey in this thesis could be conducted again with the inclusion of a high number of stakeholders so that subjectivity in the approach can be eliminated. Furthermore, the weighting system used in the tool is relatively simple; in the future, more sophisticated systems for the evaluation of features could be developed by also adding the considerations of the budget constraints and resources available in the region where a particular building is constructed. Last but not least, the new features captured from the next generation buildings can be integrated into the tool as a feature, or strategies could be widened with the lessons learned from the current buildings. Thus, the tool could be continually improved.

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APPENDICES

A. The questionnaire survey for the investigation of IB definition

This questionnaire explores the common characteristics of intelligent buildings – IB with the aim of contributing to the continued evolution of the concept and guiding the decision-making during their design. The answers of this survey will be used for only academic purposes and all the survey results will be shared with those who participated in this survey. The survey will take 10-15 minutes and composed of two parts:

Part 1 - General information about the participant

The questions in this part are designed to collect information on your professional experience. Please provide relevant information by marking the box and filling gaps.

Profession:
- ○ Civil Engineer
- ○ Electrical Engineer
- ○ Mechanical Engineer
- ○ Architect
- ○ Other, please specify______

Expertise:
- ○ Owner
- ○ Facility Manager
- ○ Construction Manager
- ○ Contractor
- ○ Designer
- ○ Consultant
- ○ Researcher
- ○ Other, please specify______

Years of experience in the area of built environment:
- ○ 0 – 3 years
- ○ 3 – 5 years
- ○ 5 – 10 years
- ○ More than 10 years

Nationality: ____________

Countries in which you have relevant experience: ______________

Part 2 – Definition of intelligent office buildings

In this part of the questionnaire, the information regarding the parameters of "intelligence" in buildings is presented.

Question 1: How do you define an intelligent building? Based on your personal experience, what features are necessary to denote an office building as "intelligent" ?

Question 2: According to your practical experience, what features are usually considered in the construction industry to design and build an intelligent office building in practice?

Question 3: Can you please give a real case example (or cases) for an intelligent office building? (Location, size, app. construction cost etc.)

Part 3 – Features of an intelligent office building

In this part of the survey, the features which have a contribution to three essential characteristics of an intelligent office building, "*responsiveness*", "*connectedness*" and *"environmental consciousness*" are provided for your evaluation.

Please rate each parameter based on their level of importance to each characteristic property. The evaluation scale is 1- Not important, 2- Weakly important, 3- Averagely important, 4- Essentially important, 5- Very important.

NOTE: After the completion of this questionnaire survey, a further study on performance assessment of IBs will be conducted. Please choose 'Yes' if you volunteer to participate in that study.

○ Yes ○ No

Intelligent Features		Importance level				
		1	2	3	4	5
Building Management System (BMS)						
HVAC system	Pre-programmed zoning control in Building Management System (BMS)					
	Self-adaptive control based on real-time indoor/outdoor environmental data (weather and occupant behavior pattern/feedback)					
	Degree of control by the occupants for radiant temperature and fresh air /odor)					
Lighting management system	Pre-scheduled zoning control in BMS					
	Self-adaptive control based on real-time indoor/outdoor environmental data (daylight intensity and occupant behavior pattern/feedback)					
	Degree of perceived control by the occupants for the levels of artificial lighting, daylight shading and glare					
Façade	Pre-programmed active control of façade elements in BMS for daylight, solar gain and ventilation					
	Self-adjusting façade elements based on real-time environmental data (weather and occupant behavior pattern/feedback) with learning ability					
	Manual control of façade elements for daylight, solar gain and ventilation					
Real-time surveillance of occupant behavior for data collection						
Occupant feedback about building in terms of comfort and satisfaction						
Advanced Technology (ADV)						
Advanced safety management system						
Advanced security monitoring and access control system						
Advanced fire detection and protection system						
Advanced vertical transportation system						
Smarter cleaning and maintenance of the building						
Remote control ability						

Intelligent Features	Importance level				
	1	2	3	4	5
Level of integration (ex. integration of HVAC with fire alarm and video surveillance)					
Self-learning ability for the prediction of future uncertainties					
Integrity of systems in the long term					
Installation of a structured cabling infrastructure network					
Availability of wireless communication network					
Automatic fault detection ability of all systems and structural elements of the building					
Design Management (DM)					
Knowledge of the occupant on how the building operates					
Easy of space reconfiguration and extension for the changes in size and work practice					
Place allocation to employees according to their preferences or mood					
Connection to smart built environment (smart power grid, smart utility networks and service providers)					
Degree of flexibility of façade elements for renovation and future changes					
Easy access to fiber-optic network					
Reduction/Reuse/Recycle of waste					
Reduction of heating, cooling, lighting and ventilation load					
Application of natural/passive design strategies instead of active systems					
Reduction/Reuse/Recycle of water					
Easy upgrade/renewal of the systems for advancement of technology					
Installation of renewable energy systems (ex. solar, wind and geothermal)					
Improved communication for teamwork and collaboration					
Access to outdoor space both visual and physical					

Question 4: If you have any further comment which is not considered in this survey, please write down below.

B. Form for validation of Intelligence Assessment Tool for Office Buildings (IATOB)

Expertise:
- ○ Owner
- ○ Facility Manager
- ○ Construction Manager
- ○ Contractor
- ○ Designer
- ○ Consultant
- ○ Researcher
- ○ Other, please specify______

Profession:

Experience in years:

Place of experience:

Description

In the literature, there still is no consensus on what an intelligent building is. Therefore, the meaning of intelligence in buildings was searched by using a questionnaire survey. Then, based on the analysis of survey results, the measurement of building intelligence, a tool named Intelligence Assessment Tool for Office Buildings (IATOB) was developed. The conceptual framework of the tool for the measurement of intelligence level focuses on three main aspects: Building Management, Advanced Technology, and Design Management.

Building management involves aspects of controllability of systems and data collection; *advanced technology* encompasses aspects of building systems, connectivity with the surrounding, and *design management* covers the aspects of space management, architectural form, and materials.

Here, we ask you to think of an existing building and assess its intelligence following the steps explained below.

Before evaluating the building using the tool

Please consider an office building which is *intelligent* according to you, name and location of the building. (Since the specific features and information will be asked during the evaluation, choosing a building that you are familiar with will be better):

Step 1. Please provide the strengths and weakness of the building according to you:

Strengths:

____

Weakness:

____

Step 2. Before assessing the building with the tool, according to your personal view, what would be this building's overall intelligence score? Please give a score between 0 and 100.

Evaluating the building using the tool

Step 3. Please evaluate the building using the tool (attached excel). You will need to enter inputs regarding some intelligent features.

____

After evaluating the building using the tool

Step 4. After the evaluation with the IATOB tool, please respond to the following questions (This part will also be discussed during the online meeting):

I. Is the score you assigned in Step 2 similar to the overall intelligence score obtained from the tool?

____

II. If not, what would be the reason according to you? (ex. weights, missing features in the tool, miscalculation)

____

III. Are the points earned/lost from each aspect reasonable to you?

____

IV. What do you think about the proposed strategies? Are they helpful for the improvement of building intelligence? Are there any other strategies available?

____

V. What decisions could be made with the proposed strategies? Please write down the advantages and disadvantages of these strategies.

____

C. List of the proposed strategies in the IATOB

Intelligent Features	Proposed Strategies
BM1	Establishment of an online platform to enable occupant provide feedback (web-page or via smart phone application)
BM2	Intelligent Lighting System with occupancy, daylight sensors for the light intensity, angle of protection, solar radiation
BM3	Auto adjustment of HVAC system by sensing the outdoor temperature and humidity
BM4	Ability to control via personnel computer or smart phone application Split thermal ventilation systems Micro-zoning decrease one zone Operable windows by the occupants
BM5	Utilization of split ambient and task lighting Decrease zone size to one per person Ability to control via personnel computer or smart phone application Operable shading system by the occupants
BM6	Responsive façade elements (blinds, shading and glazing) to harvest daylight and passive solar gain
BM7	Manual operation of shading system and windows
BM8	Programmed timers for shading elements and windows
BM9	Programmed timers for HVAC System
BM10	Programmed timers for lighting Digital Addressable Lighting Interface (DALI) Automatic lighting or shading control
BM11	Employee's intelligent monitoring system to track user movements and activities Wireless sensor network for detecting occupants
ADV1	Wire for primary services, wireless for value added mobility
ADV2	Connection to the smart power grid Connection to smart utility networks
ADV3	Connection to an optical fiber LAN system

Intelligent Features	Proposed Strategies
ADV4	Automatic notification to fire department when the fire incident happens Integration with vertical transportation systems and power supply systems Installation of CCTVs for fire monitoring Application beyond the requirements of building fire safety regulations
ADV5	Integration with fire alarm, video surveillance and HVAC systems Integration of Energy Management System, Building Automation System and Structural elements Full Integration of Building Management System with facility management system and structural elements
ADV6	Water leakage detection system Monitoring of structural elements
ADV7	Sensors for the monitoring the time for cleaning at the toilets Robots for vacuum cleaning and mopping
ADV8	Computerized smartcard access control system Applications further than the requirements of building regulations and policies Earthquake resistance and alarm systems Surveillance system with real time security feeds
ADV9	Ability to connect multiple locations of BMS Remote access from offsite via smart phone application
ADV10	Wire for primary services (i.e. electricity or telephone) Raised floor system installation Suspended ceiling installation Modular wiring systems
ADV11	Voice recognition system inside the elevator Ability to predict the passenger traffic and accommodate the changes with shortest waiting time Auto-controlled navigation at emergency Automated destination-controlled lift system
ADV12	Integration of the learning ability concept into the management process with real data driven for the decision making

Intelligent Features	Proposed Strategies
DM1	Application of climate responsive design strategies based on regional characteristics (i.e. well insulated envelope, double skin façade, operable exterior shading device)
DM2	Availability of extra capacity of the systems
DM3	Use of communication protocols (BACNet, Internet Protocol) suitable for all systems from a variety of manufacturers
DM4	Activation of thermal storage mass - night flushing and natural cooling Underground duct-supply air preconditioning - natural cooling Solar Chimney (natural ventilation exhaust chimney, wind +buoyancy driven, passive cooling through cross ventilation) Use of light redirection for effective daylighting Storage of energy in batteries, in hot & cold tanks, in thermal mass Storage of coolth as ice at off-peak periods
DM5 & DM6	Use rainwater for toilet flushing or garden Use of low-flow appliances Installation of greywater use system Use of environmentally friendly materials for resource recycling Composting of solid waste Separation of living waste collection for recycling Reduction of materials used Recycled and recyclable material selection
DM7	Creation of tenant guidelines on how the building operates Informing the occupant about the amount of consumed energy and water
DM8	Installation of PV panels Installation of geothermal heat pumps
DM9	Extensive shared and social spaces for collaboration Project rooms for group-works Space design inside the building to improve flow
DM10	Closeness to the windows (7 meters max. distance and depth of a room 1.5 times the window head height)

Intelligent Features	**Proposed Strategies**
DM11	Selection of the easy upgradable equipment - not disruptive to the function of the building
DM12	Isolated technical ground - separation between power wiring and data Modular, reconfigurable, adaptable ports/outlets for electricity and communication Raised floor for voice and data systems Flexible workstation pattern with relocatable infrastructure/equipment Flexible interior space/floor plan and utilization Flexibility enhanced by generous floor height (Min. 2.5m) Flexibility of lighting, air distribution, heating and fire sprinkling systems layout
DM13	Layering building elements The choice of material combination based on design of structure with the consideration of their regular replacement
DM14	Creation of space for privacy and individual concentration on tasks Creation of green spaces and gardens inside the building

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MS	METU Civil Engineering, Ankara	2012
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2017-2018	GAMA Power Systems	Project Control Engineer
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2009-2012	Eser Project and Engineering	Tender Engineer

FOREIGN LANGUAGES

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Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın İrem Dikmen TOKER

Danışmanlığını yaptığınız **Handan GÜNDOĞAN'ın "Akıllı Ofis Bina Tasarımı İçin Bir Karar Destekleme Aracı"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **097 ODTU 2020** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

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