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The Smart Building

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I. INTRODUCTION

Science and technology have already grasped so much of our lifestyle in the global economic development up to becoming highly modernized. Today, society has learned and reached the utmost state of advancement in economic development, science, and technology innovations, and the utilization of the given natural environment [12].

Digitization, one of the developments, is turning as essential in our daily living. People are privileged to experience the benefits of the different social media sites, digital pictures and videos, commercial transactions, advertising applications, and games, making us the most significant contributor in data generation [18]. As the trend becomes more evident for the past years, from the existence of smartphones, computers, environmental sensors, GPS, cameras, etc. even buildings nowadays were adjusting to integrate and cutting-edge concepts and technologies to meet the needs of users by providing and allowing experience the good quality of service.

To take a brief glimpse of the first buildings, these are constructed as a primitive shelter made from the combination of natural materials such as stones, wood, sticks, animal skins, to mention a few. These early structures, such as in Figure 1, have the same purpose as the buildings we see today. However, they hardly resemble the steel and glass which were used as materials, that is, to provide comfortable space for people staying inside. On the other hand, today's buildings are built with the concatenation of complex structures, systems, and technology. And as we enter the age of modernization, buildings' components are being enhanced with innovative lightings, security, heating, and ventilation, to mention a few [4]. However, upon considering the impact of buildings on the electrical grid, environment, and organizations' mission, building owners weren't satisfied with the concept of their buildings that were only able to provide comfort, light, and safety. This challenge triggered the emergence of the smart building.

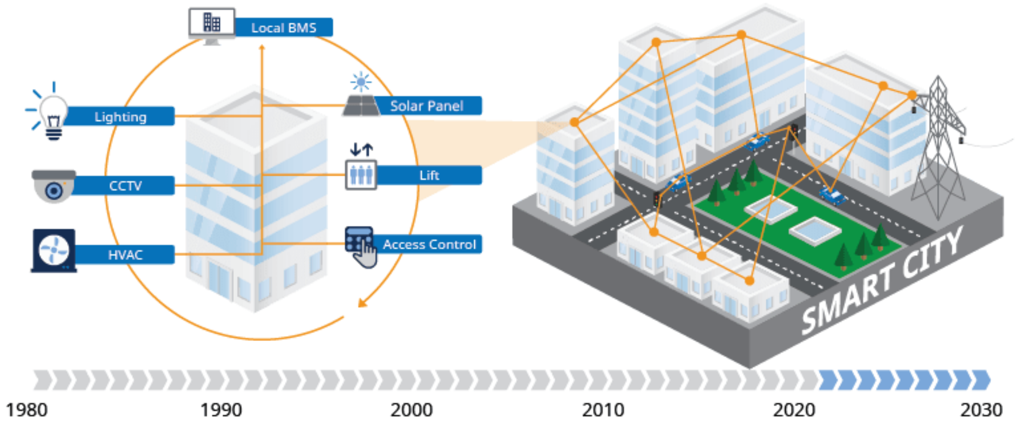
Source: https://melbourneurbanist.com/2011/05/11/why-do-we-love-old-buildings-so-much/
Figure 1. Melbourne Town Hall Chamber, 1968.

As early as 1980s, the concept of smart building has already been discussed. In 1984, real estate developers were described in a New York Times article, creating buildings intelligent buildings defined as the marriage of old-fashioned building management and telecommunications [13]. In the next decades, science and technology did its part to seamlessly fulfill smart buildings' objectives - to minimize energy cost supporting a robust electric grid and mitigating environmental impact.

Generally, the objective of this paper is to understand what a smart building is. Specifically, this will further discuss the benefits, features, and examples of smart buildings we have today and the determination of building intelligence quotient.

II. SMART BUILDING

A smart building, also called as "intelligent building", is any structure that uses programmed processes to automatically control operations that go on in the building between the systems to optimize the building's performance, which includes heating, ventilation, air conditioning, security, and other systems [13, 16]. A smart building collects data using sensors, actuators, and microchips. The data will be managed according to a business' functions and services that will help owners, operators, and facility managers improve asset reliability and performance by reducing energy use, minimizing the environmental impact, and optimizing the available space of buildings [2,9].



Source: https://www.forescout.com/company/blog/smart-buildings-trends-and-challenges-for-a-secure-future/

Figure 2. Evolution of buildings.

Old buildings are much far different from the buildings of today. The buildings we had decades ago provided the essentials such as shelter, safety, temperature control, etc., wherein the performance is constant. On the other hand, newer buildings have become smart buildings. They are constantly subjected to change as much as they are considered living organisms connected to a network with intelligent and adaptable software to operate in a more efficient, flexible, interactive, and sustainable way [7].

In Figure 2, the evolution of how buildings change is shown. Smart buildings' idea originates in the increase in the integration of advanced technology to buildings in their systems. The buildings' whole life cycle can be remotely operated and controlled for convenience, comfort, and, most importantly, a cost energy-efficient manner [10]. It is widely accepted that the use of new technologies is a fundamental prerequisite to achieve the realization of smart buildings, which includes, but not limited to, sensor deployment, big data engineering and analytics, cloud and fog computing, software engineering development, and human-computer interaction algorithms, etc. Among these supporting technologies, one of the trending areas is developing the Internet of Things (IoT) [14]. The IoT sensors and building automation control everything from lighting and energy usage to user-centric functions such as wayfinding and conference room scheduling [6]. Figure 3 shows the four main paradigms of IoT definitions, which were elaborated in the study of Jia et al. (2019).

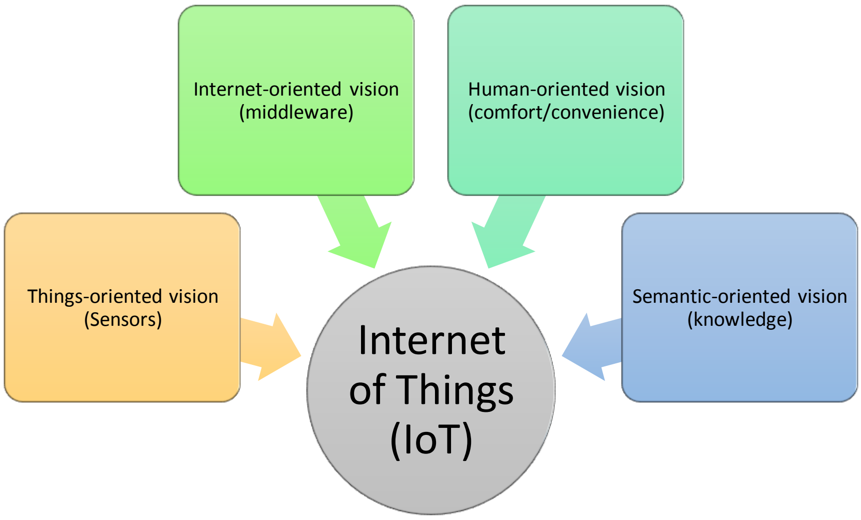


Figure 3. Four main paradigms of IoT definitions (Adapted from Jia et al., 2019).

Over the past 20 years, many different buildings have been labeled as intelligent. However, the application of intelligence in buildings has yet to deliver its true potential. For the last three decades, the so-called intelligent buildings (IBs) were only a conceptual framework for representing future buildings. Today, IBs are rapidly becoming inherent constituents of influential policies for the design and development of future buildings. Undeniably, urbanized areas are expected to be highly influenced by IBs to promote smart growth, green development, and healthy environments. Various studies have tried to map the evolution of the concept of IBs. The emergence of information and communication technology (ICT) and the development of automation, embedded sensors, and other high-tech systems are key elements in IBs [8].

Smart buildings have not grown an interest in people without the promising advantages they bring. There were several reasons why owners prefer the buildings. A company known as MGM acquires several hotels with various types of building automation systems. MGM was able to save a large amount of money, about hundreds of thousands of dollars, all because the company operates efficient energy systems.

"When you pay in excess of $1 million monthly for energy, even 5% savings is a huge amount of money," said John Leslie, the energy manager and building automation of MGM Resorts, in his interview with Siemens [16].

Another issue for buildings is building overheads. While these are necessary business expenses, they are often put to waste because of not wise usage. Lights, air conditioning units, or heaters were switched on in rooms where there are no people to use them. This is the smart building's primary goal - to avoid waste of energy and resources and, at the same time, cut the cost and improve energy efficiency.

2.1. Features of smart building

There is no single set of standards in putting up smart buildings to begin with. But the common asset of the integration and linking core systems such as lighting, power meters, water meters, pumps, heating, fire alarms, and chiller plants with sensors and control systems. Even elevators, access systems, and shading can become part of the system at a more advanced stage. Smart buildings look beyond the building equipment within their four walls; thus, the following are some of the promising features adapted from Bell (2019):

2.1.1. Connected systems

The most fundamental feature of a smart building is having all the core systems and components linked and connected. The lightings, air condition, fire alarms, power, and others are connected; thus, the systems and components can share data.

2.1.2. Sensors

Sensors are another significant feature of a smart building. The smart buildings can collect data to inform decision-makers about where to allocate resources through sensors' availability. Sensor technology controls everything from the lighting and energy usage of physical spaces to user-centric functions, such as wayfinding and conference room scheduling [6].

2.1.3. Automation
This is another crucial factor that completes the promising features of smart buildings. The corresponding data from the connected components are being analyzed by the systems incorporated, and this is done repeatedly. This monitoring allows for automated adjustments to control conditions across an entire building.

2.1.4. Data
Smart buildings generate a large volume of valuable data that allows for smooth and more efficient overall performance, which regular buildings simply won't be able to.

2.2. What are the benefits of smart buildings?

One of the biggest reasons why a building owner wants a smart building is the potential to increase the building's value and marketability [6]. The building owners can transform their buildings so that their occupants will experience a more customized workspace when the technological capabilities of buildings continue to grow. Some of the benefits of smart buildings are discussed as follows:

2.2.1. Increase productivity of occupants
Because of smart buildings, many businesses emphasize employee retention, engagement, and satisfaction. The almost perfect air quality package, physical comfort, security, sanitation, lighting, and even room and space availability are the factors that drive occupants to their optimum level to perform well.

2.2.2. Reduction of energy consumption
Smart buildings are known to be more energy-efficient and more cost-effective compared to ordinary buildings. Having a smart building is desirable because it could increase energy savings. With a smart building, data can be collected continuously and utilized to ensure the building management system's baseline is saving as much energy as possible.

2.2.3. End of guesswork
The use of sensors and cameras provides precise data on how the building is being used, which can be converted into insightful decision making. Space utilization can be improved based on actual data, as the building generates actionable, living intelligence automatically.

2.2.4. Significant operational savings
This includes the savings that can be made in terms of everyday spend and maintenance on equipment. It also extends to the potential savings that are offered by identifying underutilized resources and the potential for growth into unused spaces.

2.2.5. Data protection
Equipment, such as thermal sensors, measures data without using identifiable images of staff or the public.

2.3. Functions of a smart building

Smart buildings are comprised of several systems connected and linked together with the aid of technology. A smart building connects the structure itself to the functions to fulfill the following adapted from the article in Building Efficiency Initiative (2011 The latest buildings were created with quite complex features and control systems with complicated programs. Most of the information is analyzed and transported from one device to another whose sole purpose is to preserve data privacy and security. A smart building will have connectivity between all the equipment and systems in the building. For example, the building security system will relay the information to specific equipment programs to increase cooling when many people are occupying space. Therefore, when a building has its systems linked together (security, air conditioning, lighting, etc.) and will send data to each other, this will lead to higher efficiency, lower-cost operation, a more secure workplace, and more comfortable.

2.3.2. Connecting people and technology

The people that run a smart building are considered a crucial component of their intelligence. That means that the software and hardware for the linked systems will not perform what is designed to do without people to operate them to work more effectively. Smart buildings are designed tools to enhance the existing efforts of people. As it continues to evolve, sharing information between the components and systems will serve as a platform for future innovation.

2.3.3. Connecting to the bottom line

Like the internet, the smart building can also be considered a supersystem since it links all its components and systems. The interconnection of the systems serves its purpose by using the data to reduce operating costs by optimizing the operation and increasing its efficiency.

Since the systems and components in a smart building share and create open access of information to each other, this allows for the development of new applications that can save time, energy, operating costs, etc.

2.3.4. Connecting to the global environment

Translation software gathers data from all automated systems to merge it into a common platform for analytics and reporting. This helps executives manage sustainability and carbon footprint management to see their big performance, no matter how many buildings or geographic locations are involved. When data is accessible anytime and anywhere, managers can make accurate decisions for profitability's immediate impact.

2.3.5. Connecting to the smart power grid

A smart grid may be programmed to read the weather forecast and anticipate an increase in temperature. This will increase the demand for the next few hours. Smart building can accept offers from utilities to pay the price for every kilowatt-hour drop usage from the usual electricity usage by activating an internal demand-reduction mode and reducing its load.

2.3.6. Connecting to an intelligent future

Smart building isn’t just about saving energy and contributing to sustainability goals. More importantly, they extend up to the safety and security of both human and capital resources. The smart building allows innovation for future applications through the accessible form available, which will help operators and managers in decision-making. Summing up the advantages, businesses will operate at a new level of efficiency by leveraging the connection between the systems and components. These benefits can extend through the entire lifetime of buildings, from modeling and design to renovation and beyond.

2.4. Examples of Smart Building

To show how smart building utilization in the real world works, some of them are being used today.

2.4.1. Capital Tower, Singapore

This 52-story office building shown in Figure 4 won the Green Mark Platinum Award for its construction and design, along with its energy and water efficiency [6]. The Capital Tower is composed of several built-in energy-efficient systems such as an energy wheel recovery system in its air-conditioning unit, motion detectors, double glazed glass windows, etc. In addition to that, this 68 000 square-foot building has few amenities, which include a sky lobby, a fitness center, pool, childcare, and dining options.

Source: https://commons.wikimedia.org/wiki/File:Capital_Tower_Tone_Mapped_-_Ricky_W.jpg

Figure 4. Capital Tower of Singapore

2.4.2. Hindmarsh Shire Council Corporate Centre, Australia

The Hindmarsh Shire Council Corporate, shown in Figure 5, is a known smart building in the world located in Australia. Melbourne-based architect firm k20 Architecture's main objective is to improve energy efficiency while enhancing the office environment for employees. The architects took advantage of the building's location, where it is exposed to extreme temperature conditions, by building a series of underground thermal chambers and a ventilation system under the floor in to draw in fresh air from the exterior [6].

Source: http://yourlearningorganisation.com/2013/08/30/green-building-hindmarsh-shire-council-centre/
Figure 5. Hindmarsh Shire Council

2.4.3. Duke Energy Center, Charlotte, NC

Wells Fargo owns this building shown in Figure 6 with a 51-floor skyscraper (48 occupied stories) and home to Duke energy. This received the highest green certification, LEED Platinum. Approximately 10 million gallons of harvested water from rainwater, groundwater, and HVAC condensation within a year is reused, which meets roughly 80% of the cooling tower's water needs and 100 % of the building's irrigation needs. Moreover, the landscaped roof garden helps reduce stormwater run-off, and at the same time, the plants capture excess heat [6].

Source: http://waldolydeckersjournal.blogspot.com/2017/12/the-duke-energy-tower-eye-of-sauron.html

Figure 6. Duke Energy Center, Charlotte, NC

2.4.4. The Crystal, London

This is one of the world's most sustainable buildings. The Crystal in London, shown in Figure 7, designed by Siemens, is 100 % electric, and the solar panels generate about 20 % of its power. It makes it more attractive because energy usage is monitored extensively, leading to a result where its carbon emissions are about 70% lower than comparable office buildings in the UK.

Source: http://2017.copywritingconference.com/venue/

Figure 7. The Crystal of London

2.4.5. Burj Khalifa, Dubai

Dubai, shown in Figure 8, is a world leader in the intelligent building movement. Burj Khalifa isn't just about being the world's tallest building, but also, it has its design as always been on the edge of innovation.

With the help of Honeywell, it's now one of the smartest and most sustainable buildings. Now, facility managers have reduced total maintenance hours by 40 % [6].

Source: https://misstourist.com/burj-khalifa-tickets-price-uae/
Figure 8. The Burj Khalifa Tower

2.4.6. The Edge (Deloitte HQ) in Amsterdam, Netherlands

The building shown in Figure 9 is dubbed as the "Smartest Building in the World" by Bloomberg. The smartphone app is used in optimizing the efficiency and productivity of its employees. It can automatically direct employees to an open parking spot for their cars, direct them to an open workstation, and the app knows the employees' preferences in terms of light and temperature then the environment performs accordingly. Apart from that, it has the world's most efficient aquifer thermal energy storage system. The Edge is known as the greenest building globally, with a rating of 98.4%, the highest sustainability score ever awarded by the British rating agency BREEAM [11, 15].

Source: https://www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building/s
Figure 9. The Edge of Amsterdam.

2.5. Building Intelligent Quotient

To distinguish whether a particular building is worth to be chosen as the “best” smart building, Volkov (2013) introduced the formula, Building Intelligent Quotient (BIQ), that can be used in evaluating and measuring the building intelligence. Table 1 contains the terms which are required in understanding the idea.

Table 1. Terms in BIQ calculation.

Variable	Description
X	A set of all parameters of the building (e.g. temperature, light intensity in any building zone)
X_1	A subset of the observed building parameters
P	A set of all processes that change values of the building parameters which includes natural processes such as outside temperature changes, therefore, temperature change zones.
P_1	A subset of processes which change the values of observed building parameters
P_2	A subset of controlled processes which can change the values of the observed building parameters
R	A set of all controlling processes over changes of values of the observed building parameters.
R_1	A subset pf processes that control changes of the observed building parameters which are functionally adaptive to the own state space X_1

To estimate the automation level and intelligence of a building, equations 1 and 2 can be utilized in the calculation, respectively:

$$BIQ = \frac{Q(P_2)}{Q(P_1)} \tag{1}$$

$$BIQ = \frac{Q(R_1)}{Q(R)} \tag{2}$$

where Q is a set of function,

$$Q(R) = \sum\nolimits_{r \in R} c_r \tag{3}$$

$$Q(R_1) = \sum\nolimits_{r \in R_1} c_r \tag{4}$$

and c_r is a quantitative expression of the significance of a process that changes values of building’s parameters. Furthermore, the closer calculated value of BIQ to 1, the better smart building solution.

III. CONCLUSION

Smart buildings are already a part of the transition process of cities towards becoming smarter and more sustainable. The concept of the smart building made changes to the standard buildings over time. This is to fill in the drawbacks posed by the usual concepts of buildings. Urban areas are expected to be highly influenced by smart buildings to promote smart growth, green development, and healthy environments.

Some of the factors why building owners want a smart building were specified to increase their potential by increasing their value and marketability. Smart buildings help increase occupants' productivity, reduce energy consumption, end the traditional guesswork, protect data, and lead to significant operational savings. These benefits are because of smart building's promising features such as connected systems, automation of processes, availability of sensors, and data. Some real smart buildings were also presented to imagine how smart buildings in real life are so promising.

Overall, smart buildings are efficient in optimizing and overcoming the challenges of buildings decades ago to become more sustainable by improving the asset reliability and performance, optimizing how space is used, and minimizing the environmental impacts of the buildings.

REFERENCES

[1]. Alptekin, C. (2019). Real world results: 4 benefits of smart buildings. https://www.iotacommunications.com/blog/real-world-results-4-benefits-of-smart-buildings/. Date retrieved: October 22, 2020.

[2]. Asadian, E., Azari, K., & Ardabili, A. K. (2018). Multicriteria selection factors for evaluation of intelligent buildings--- a novel approach for energy management. http://dx.doi.org/10.1016/B978-0-12-813734-5.00005-6.

[3]. Bell, T. (2019). What is a smart building?. https://www.trueoccupancy.com/blog/what-is-a-smart-building. Date retrieved: October 19, 2020.

[4]. Building Efficiency Initiative. (2011) What is a smart building?. https://buildingefficiencyinitiative.org/articles/what-smart-building. Date retrieved: October 19, 2020.

[5]. Catrone, N. (2019). Why is a smart building desirable to building owners?. https://facilityexecutive.com/2019/09/why-is-a-smart-building-desirable-to-building-owners/. Date retrieved: October 22, 2020.

[6]. Dukes, E. (2018). 5 Intelligent building examples we can’t stop talking about. https://www.iofficecorp.com/blog/intelligent-building-examples. Date retrieved: October 22, 2020.

[7]. Froufe, M. M., Chinelli, C. K., Guedes, A. L. A., Haddad, A. N., Hammad, A. W. A., Soares, C. A. P. (2020). Smart buildings: systems and drivers. Buildings 2020, **10** (153); doi:10.3390/buildings10090153
[8]. Ghaffarianhoseini, A., Berardi, U., Alwaer, H., Chang, S., Halawa, E., Ghaffarianhoseini, A., & Clements-Croome, D. (2015). What is an intelligent building? Analysis of recent interpretations from an international perspective. Architectural Science Review. doi: 10.1080/00038628.2015.1079164.
[9]. Huang, Q., Lu, C., & Chen, K. (2017). Smart building applications and information system hardware co-Design. Big data analytics for sensor-network collected intelligence. http://dx.doi.org/10.1016/B978-0-12-809393-1.00011-8
[10]. Jia, M., Komeily, A., Wang, Y., & Srinivasan, R. S. (2019). Adopting internet of things for the development of smart buildings: A review of enabling technologies and applications. https://doi.org/10.1016/j.autcon.2019.01.023
[11]. Randall, T. (2015). The smartest building in the world. https://www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building/. Date Retrieved: October 22, 2015.
[12]. Saito, N. (2015). The concept of ecological smart home network. Ecological design of smart home networks. http://dx.doi.org/10.1016/B978-1-78242-119-1.00001-1
[13]. Sinopoli. (2010). What is a smart building? .doi:10.1016/B978-1-85617-653-8.00001-6
[14]. Totonchi, A. (2018). Smart buildings based on internet of things: a systematic review.
[15]. The Comfy Team. (2017). Top 8 smart buildings from around the world. https://www.comfyapp.com/top-8-smart-buildings-from-around-the-world/. Date retrieved: October 22, 2015.
[16]. Tracy, P. (2016). What is a smart building and how can it benefit you?. https://www.rcrwireless.com/20160725/business/smart-building-tag31-tag99. Date retrieved: October 19, 2020.
[17]. World Construction Today. Top 10 benefits of having a smart building. https://www.worldconstructiontoday.com/articles/top-10-benefits-of-having-smart-buildings/. Date retrieved. October 22, 2020.
[18]. Venticinque, S. & Amato, A. (2018). Smart sensor and big data security and resilience. https://doi.org/10.1016/B978-0-12-811373-8.00006-9
[19]. Volkov, A. (2013). Building intelligent quotient: mathematical description. Applied Mechanics and Materials Vols. 409-410, 392-395. Trans Tech Publications, Switzerland. doi:10.4028/www.scientific.net/AMM.409-410.392