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The distinctive features of "smart" buildings

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Abstract

"Smart" buildings is an emerging technology. Very often a building "intelligence" is confused with just a building automation. This paper explores distinctive features of "smart" buildings. It was figured out that a formal definition and a quantitative measure of a building "intelligence" do exist. However, due to non-deterministic nature of Artificial Intelligence, a simulation of building operations is required to calculate Building Intelligence Quotient.

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1. "Smart" building definition

Understanding distinctive features of "intelligent" buildings is very important. "Smart" buildings differ from usual buildings, so designing process is different as well. Let us try to answer a question what a "smart" building is?

All informal "smart" building definitions can be divided on two main types. Let us take a look on an example of the first type. The online oxford dictionary definition is: "a home equipped with lighting, heating, and electronic devices that can be controlled remotely by smartphone or computer: you can contact your smart home on the Internet to make sure the dinner is cooked, the central heating is on, the curtains are drawn, and a gas fire is roaring in the grate when you get home" [1]

What is wrong with this definition? All decisions are initiated not by a "smart" home, but by smart inhabitants. Unfortunately, this definition reflects the current state of the market. Very often "smart" buildings are confused with just automated buildings. Most commercial products can provide only the ability to use a remote control and

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predefine behavior of different engineering systems. It has been shown that there is no any intelligence in such systems and they can even inconvenience inhabitants. [2]

But, let us take a look on another definition: "Instead of being programmed to perform certain actions, the house essentially programs itself by monitoring the environment and sensing actions performed by the inhabitants(e.g., turning lights on and off, adjusting the thermostat), observing the occupancy and behavior patterns of the inhabitants, and learning to predict future states of the house." [2]

We can see a dramatic difference in the definitions, in the second one a home learns from its inhabitants, adapts to their life cycle and initiates all decisions itself. In this paper, talking about "smart" buildings, we will keep in mind the second definition.

2. "Smart" building benefits

Having reviewed state of the art projects that aim to develop a "smart" home that comply with the second type of definitions such as: The Adaptive Home (University of Colorado) [2], House_n (Massachusetts Institute of Technology) [3], The Aware Home (Georgia Institute of Technology) [4], MavHome (The University of Texas at Arlington) [5], it is safe to conclude that potential benefits of "smart" buildings are wider than just a remote control. It includes:

- inhabitants comfort: "Smart" homes learn from inhabitants behavior and tries to maximize their comfort.
- energy savings: "Smart" buildings can significantly reduce energy consumption. It is profitable for building owners as it leads to costs cut.
- time saving: "Smart" buildings can save a lot of time by automating daily routines.
- safety: "Smart" buildings can detect fire, water and gas leaks. "Smart" buildings have a self-diagnostic system and warns inhabitants when equipment becomes faulty or performance starts to decrease.
- expert systems: Embedded expert systems could contain knowledge about any domestic or industrial area.
- health and care: In all "smart" buildings decisions health of inhabitants has the highest priority. It is reflected in appropriate temperature, light intensity, air condition parameters, etc.
- assistive domotics: "Smart" homes can improve the quality of life of the elderly and the disabled living alone by providing a safe and comfortable environment. Homes assist in daily routines, alerts social services and relatives if emergency help is required, reduce a sense of isolation by connecting with other people through the internet and so on.

3. "Smart" building components

What distinguishes a "smart" building from normal and makes it smart?

3.1. Hardware

First of all, "smart" buildings need an ability to recognize what's happening with an environment (inside and outside a building), needs something like human senses. For this purpose "smart" buildings are equipped with sensors and meters. So, a building can determine rooms' occupation, light intensity, inside and outside temperature, carbon dioxide level, noise level, detect a gas leak and so on.

Besides observing the environment, a building also should be able to change its state. For this purpose "smart" buildings are equipped with devices and actuators that can control various engineering systems like lighting, heating, air conditioning, entertainment system and so on.

3.2. Software

Sensors and meters provide only raw information. A "smart" building needs to extract useful information, learn from this information, make decisions and even predict future state of environment and people activities. It is done by special software which is an artificial intelligence of a building. Frankly speaking, true artificial intelligence still has not been built, but a lot of applied techniques was developed on the way toward AI. One of the most widely used techniques is a machine learning. Machine learning is a part of all modern developments of "smart" buildings. Software is a vital part of any "smart" building.

3.3. Network

To allow the building to act as a whole- a communication network is required. It connects all devices between each other and with the artificial intelligence component. It is the nervous system of a building.

Hardware, software and network together we will call a "smart" building solution.

4. Building Intelligence Quotient

Even though informal definitions are quite intuitive, they can't be used in engineering practice. Designers want to know how to choose the best "smart" building solution for a particular building? The interesting question is, what the best means? To say that something is better than another we need a formal, ideally in a quantitative expression, definition of the "best". Prof. Volkov introduced a formal definition of an "intelligent" building and formula (building intelligence quotient- BIQ) that can be used as a measure of building "intelligence" [6,7]. Also BIQ shows the difference between building "intelligence" and building automation, two types of definitions we were concerned at the beginning of the article. For detailed information and deeper understanding of BIQ take a look on the original articles [6,7], here we will focus only on applying this theoretical tool to our task. Below the list of terms which are required for understanding the idea.

X - a set of all parameters of the building. Might be anything, for example, temperature, light intensity in any building zone.

X_1 - a subset of the observed building parameters ($X_1 \subset X$). Observed, in the context of our task, means parameters that can be measured automatically by "smart" building's sensors and meters and acknowledged by building AI. Obviously that amount of observed parameters dramatically fewer than amount of all building parameters.

P - a set of all processes that change values of the building parameters. It is a huge set of processes that includes: natural processes, for example, outside temperature changes and, as consequence, temperature change in particular building zones; and technical processes, for example, operation of a HVAC system that also causes temperature change in particular building zones.

P_1 - a subset of processes which change the values of observed building parameters ($P_1 \subset P$). In other words, processes that change the parameters that can be measured automatically by "smart" building sensors and meters and acknowledged by building AI.

P_2 - a subset of controlled processes which change the values of observed building parameters ($P_2 \subset P_1$). Controlled, in the context of our task, means that inhabitants can control this process. For example, inhabitants can't control outside temperature changes, but can control a HVAC system using thermostat.

R - a set of all controlling processes over changes of values of the observed building parameters.

R_1 - a subset of processes that control changes of the observed building parameters which are functionally adaptive to the own state space X1 ($R1 \subset R$). In the context of our task it means that such processes are initiated by building AI and change values of building parameters using "smart" building devices and actuators.

To estimate automation level of a building we can use Eq. 1.

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

To estimate "intelligence" level of a building we can use Eq. 2

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

Q is a set function.

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

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

c_r- a quantitative expression of the significance of a process that changes values of building's parameters. In the context of our task we also can include in c_r functional (accuracy) and non-functional (learning speed and latency) metrics of a process.

The closer BIQ to 1, the better "smart" building solution.

5. Calculating Building Intelligence Quotient

The BIQ formula is very simple itself, the biggest challenge is to get an input for the formula. As "smart" building solutions are based on Artificial Intelligence, obviously, different products have a difference in accuracy. Accuracy depends on a system itself, on a particular building, on a building's functional purpose and on an inhabitants' behavioral patterns. Accuracy might change during the building's life-cycle depending on the amount of accumulated data. Interestingly, increasing the amount of data might as improve accuracy (the more statistic the better, law of large numbers) as make it worse (for example, overfitting in algorithms based on neural networks [2]). Except system accuracy, it also matters how fast the system learns and how fast the system is (latency). This evidence suggests that BIQ can't be calculated analytically, without simulating building processes (environmental changes and inhabitants activities) to see how "smart" building solution will cope with it. Such simulation can be implemented in scope of building functional model which will be described in further publications.

6. Summary

After reviewing the current state of the market and academics researches in the "smart" buildings field, it was pointed out that the definition of a smart building is very vague and a building "intelligence" is often confused with a building automation. However, potential benefits of "smart" buildings are much wider. The appropriate theoretical basis (Building Intelligence Quotient) which separates these two notions and can be used for evaluating buildings "intelligence" does exist. Due to probabilistic nature of machine learning algorithms and complexity of a building as a system, it is impossible to get an input for BIQ formula analytically. So, a development of a functional model of building processes (environmental changes and inhabitants activities) is required to translate this idea into life.

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