ROLE OF INDUSTRY 4.0 TECHNOLOGIES IN SMART BUILDINGS-A COMPREHENSIVE SURVEY

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ABSTRACT

In recent years, Construction industry attracts the people across the globe by providing unimaginable facilities with the help of the latest technologies such as Artificial Intelligence (AI), Internet of Things (IoT), Big data (BD), Cloud Computing (CC), Machine learning (ML), Cyber Physical Security (CPS) systems and other relevant technologies under one roof. Industry 4.0 proclaims that these technologies revolutionize various sectors to be very smart. Smart building, Smart automation, Smart cities, Smart grid, Smart healthcare and Smart Apparel production become the fortunate fields due to Industry 4.0 technologies. Robots used in construction of large structures are the proven success story of AI. IoT has already set its path strongly in almost all the sectors and smart building too. The evolution of BD, CC and ML has made hospitals to be smart. CPS is also an emergent technology used in many of the sectors and sets it foot step in smart building. A best combination of one or more of these technologies creates a most conducive place to live in. Smart building intents to provide the user more comfortable, energy efficient, low operational cost and highly secured services. Smart buildings are expected to provide intelligent and secured management services, adhoc cooperation between building owners and tenants for ease of tasks execution and at tenant affordable cost. This paper aims at providing an exemplary view on the extent to which industry 4.0 facilitates and contradicts the successful growth of Smart building works and implementation aspects. This study would help the civil engineers and building constructors to decide on the right choice of using the technology with respect to the dynamically changing building environment and make possible to achieve great success in the smart building projects.

I. INTRODUCTION

Technology being inseparable part of our social community and promisingly will be a vital part of all intelligent based systems and applications that facilitates our daily lives to be smart enough. Though smartness is expected in many sectors such as automation, city development, healthcare, apparel production, and electrical grids and so on, the research towards feasibility of Smart building attracts the Engineers and Technologists a lot. Researchers strive to prove the emergent technologies such as AI, IoT, BD, CC, ML and CPS would facilitate the successful implementation of Smart building to a greater extent. All of these technologies have their own characteristics and roles that could be perfectly combined in a common platform to realize Smart building like projects.

The characteristics of smart building are distributive, interoperable, decentralized control, scalable; security and reliability. Apart from these, appropriate communication network connectivity’s, effective energy management, and adaptive environmental setup are also to be decided for realizing the Smart building systems. The rest of the paper explains in detail the beneficial scenarios of using industry 4.0 technologies, their challenges and appropriateness in implementing them in Smart building projects.
Statista forecasts that the shipment of devices needed for smart homes will be increased as shown in the figure 1 in the near future. Devices required for providing security aspects; voice systems, lighting services, etc are clearly mentioned in the above figure. It is evident that the compound annual growth rate of each technology will be enormously huge in 2022 when compared to 2018.

Figure 2 and Figure 3 shows the estimate of market size of smart home market from 2016 to 2022 at global level and consumer spending amount for purchasing smart home devices from 2014 to 2023. The Figure 1,2 and 3 clearly mentions the need for industry 4.0 technologies to implement smart buildings.

II. RELATED WORK

Any research starts with the study of existing works, conduct of investigations in the specific domain, explore the feasibility of the work and trust worthiness of the content being collected. It is not sufficient to collect papers referring journals and conference proceedings alone to take up a research work, rather it is required to refer chapters from books, online digital repositories, communities, collections from reputed publishers and professional societies such as IEEE, etc. An exemplary view that covers the scope and extent to which more relevant information could be gathered is very important stand point to fulfill the effectiveness aspects of the survey being conducted. Thus, a literature review is considered to be instinctively rationalized. A typical survey includes planning, problem definition and formulation, data collection, analysis, evaluation and proper interpretation.
In the attempt of collecting relevant data based on keyword search, initially 150 papers published across one decade i.e from 2010 to 2020 were identified from various sources and examined carefully by stretching the view to its fullest depth and breadth. In the first five years of this decade, very less appropriate data was found. At the second level, 50 papers were scrutinized and further examined. Finally it is found that reasonable contributions are available in the arena of using technologies in Smart cities especially Smart buildings. These selected papers that are majorly sourced from Springer, IEEE, Science direct, and online digital libraries of Wiley and IET are reviewed. The sections 3 of this paper present the scope for using industry 4.0 in Smart buildings. The section 4 highlights the underlying challenges of using such technologies in Smart buildings. The section 5 presents the findings and further directions of opting right proportion of using technologies that promisingly improves the effectiveness of implementing Smart building.

III. SCOPE FOR USING INDUSTRY 4.0 TECHNOLOGIES IN SMART BUILDING

This section highlights the scope for using industry 4.0 technologies such as AI, ML, DL, BD, CC, IoT, and CPS appropriately in the commercial and residential buildings.

3.1 AI in Smart Building

The use of AI is not a single technology to implement in smart buildings, rather the use of a diverse number of multiple AI based technologies is implemented as per the need. Rav Panchalingam et.al in [1] mentions that the fire detection and safety aspects of building with the help of sensing technologies and intelligent algorithms are achieved through implementing AI techniques. The authors also mention that AI is very effective in achieving the smooth operation of automated systems. The use of Multi Agent Systems (MAS) is very much helpful in improving the competence and effectiveness of control systems, power usage. [1] states that the use of ML and DL address the needs of effective way of energy conservation and predict the energy consumption requirements. According to Xiao Guo et.al in [2] it is very important to enable intelligent interaction between human and the building environment to make the buildings real smart. The review also reveals that the extent to which AI has contributed towards device management, energy management, health care facilities, security aspects and robots for personal assistance. All these are achieved by properly using the facilities such as image and voice recognition, mobility tracking, data analysing, prediction and decision making techniques.

3.2 ML, BD and CC in smart Buildings

B. Qolomany et.al in [3] tells the importance of using ML and BD to make the human life very much sophisticated. The review presents the applicability of supervised learning algorithms in smart building such as classification tasks; automate home appliances, action prediction, energy management, patient monitoring, daily living activities, modelling residents’ behaviour, learning occupant’s preferences and also lighting services. The tasks of detection, recognition, prediction and optimization are the potential uses of ML in smart building environments. The author mentions that ML is needed for fire detection, smoke detection and anomaly detection, object recognition, event prediction and optimization to take better decisions. The data collected from the building are pre-processed; useful features are extracted further analyzed to get unseen insights of the data. In [26], it is stated though feature extraction is needed, feature reduction is very important step in the field of ML to discover the information with limited features. [3] emphasize that the Apache Storm, Apache Spark, Apache Flume and Amazon’s Kinesis are the best facilities available for data analysis. The result of data analysis would be the suggestions for improving the effectiveness of facilities provided in smart buildings.

In [4], Dey. M presents a ML framework that automatically detects occurrence of fault in Fan Coil Units (FCU) at buildings. The investigation is very potential towards identifying the faults that happen during heating and cooling of FCUs. The presented method predicts the behaviour of FCUs automatically in a remote fashion. The work also addresses the issue of misconception of faults in FCUs (means actually the units are not faulty but pretend to be faulty). This scenario arises because FCUs find it difficult to cope up with the change in temperature by opening the windows or by allowing the sun light inside the room. The presented method very well handles the fault and non-fault issues, especially reduces the manual workload in fault identification and informs building design efforts to maintain the buildings’ sustainability, well-being of the occupants and green efforts.

Shapi, M.K.M, et.al in [5] states that the research work considered three ML algorithms namely K-Nearest Neighbour, Support Vector Machine with Radial Basis Function and Artificial Neural Network with multilayer perceptron to devise predictive models for determining the energy consumption at commercial buildings. The
work considered two tenants and the data collected from the building has been analysed and pre-processed. AzureML and R programming are used to determine the normality of the data collected. The performance of three ML algorithms are compared and concluded that energy consumption of each tenant has different distribution characteristics. It is also stated that suggesting a single algorithm specific to a statistical analytical platform is hardly possible.

Pesic et.al in [6] emphasize that effective energy management is one of the very important priorities of smart building. It is true that the energy consumption of a building is proportionate to the number of people residing in that building and their space utilization pattern. Thus occupancy information becomes a key point in predicting the energy requirement of the building. The accurate prediction of energy requirement, its procurement and storage would enable effective energy management approach in buildings. Such occupancy patterns are derived from the occupants’ mobility within the building. The mobility data of the occupants can be obtained by the mobile phones of the occupants provided they enable Bluetooth connection. It is also possible to get availability of occupants, proximity and location information. The author clearly states that data collection, processing and building suitable ML predictive models are the right choice for analysing the occupants’ energy utilization.

In the attempt of adopting smart cities in [7], the smart buildings are implemented. IoT is the fortunate technology instrumental in bringing smart cities via smart building construction to reality. The researchers in [7] implemented Souly- an IoT system using the Docker concept which also brings in the cloud computing technology to enable communication with IoT gateway. The cloud platform used in [7] consists of an API to facilitate integration of web apps, mobile Apps and other relevant Applications in order to achieve software upgradation, security mechanism and database management.

3.3 IoT in smart building

The task of Smart building becomes more advent in terms of construction and operational efficiencies. Bakakeu et.al in [8] highlights the aspect of building CPS and IoT for Smart buildings with self-organizing properties. Tang et.al in [9] has presented a detailed review on how IoT could be combined with Building Information Modeling (BIM) and presented five different integration methods utilizing BIM’s APIs and relevant databases in order to accomplish Smart building even at the very start of construction. The Construction operation management, Health and safety management, Logistic management and facility management are practicable with the help of BIM. Jia et.al in [13] elaborates the technical requirements, usage descriptions and the goals that are to be ascertained in Smart buildings. According to Jia et.al in [13] the technical requirements specified are locating the position of targeted objects, enabling communication between various external elements, equipments and devices and also the occupant’s behaviour pattern. The major goal in Smart buildings is to provide ubiquitous environment via location based services, energy efficiency, facility management and comfort of indoor occupants.

Park et.al in [14] briefs that the role of IoT is inevitable in implementing the Smart cities project. In addition to that the author also states that Smart building is one of the important sector in Smart cities, in which building automation, building energy management, use of optimized technology for control and management based on cloud services. Plageras et.al in [15] presents a system in which temperature, moisture, movement and light intensity are monitored using sensors and a dedicated cloud server setup for completely managing the building. Ghayvat et.al in [16] attempted to provide a wellness function of the inhabitant. In addition to this, AAL services, ADL services, Object movement tracking through time series data, sensor data analysis, are also implemented. Minoliet.al in [18] explored and presented in detail the need for energy management in smart building, required sensors, Building Management System (BMS), collection of networks and cloud services. Bashir et.al in [19] presents a Systematic Literature Review as an approach for conducting survey in IoT enabled smart buildings. According to them, energy and efficiency, longevity, comfort level and satisfaction are the requirements expected by the occupants of the smart building. So the IoT ecosystem should have provision to monitor occupant’s comfort with respect to Heating, ventilation and Air conditioning (HVAC), smart metering and other facilities.

3.4 CPS in Smart Building

CPS, by definition is the integration of computation that makes use of embedded computers to monitor and control the physical processes. The intervention of CPS in Smart cities, Smart homes are appreciable to a major extent. Bakakeu et.al in [8], mentions that the integration of heterogeneous devices with other varied application domains are possible when CPS-based smart environments are implemented properly and thus interoperability between components are achieved. The authors also presented an approach which is based on OPC UA and Multi
Agent System (MAS) responsible for self description on top of a common ontology and self organization of devices respectively. The construction of Smart building needs lot of real-time communication and coordination between things and people as they are very much distributed in terms of spatial and temporal concerns. Niu et.al in [10] has deployed a framework in which IoT, CPS and Smart Construction Objects (SCOs) are integrated to accelerate the Smart building Construction Project Management (CPM) tasks at a greater speed.

Boton in [11] highlights the review of reviews about Construction 4.0 as it is very important and crucial fact to be considered for clear understanding of the technologies to be used for Smart buildings. A well streamlined and systematic review is presented in [11] regarding digitization in construction field. Jahromi in [12] mentions that the CPS helps in improving the energy efficiency by computing the parameters such as humidity, temperature, occupancy and light intensity in real-time and regulate the energy consumption. Hamdaoui et.al in [17] highlights that CPS is responsible for setting up a CP Energy System with self-adaptation, self-organization, self-healing, self-optimization, and self-energy supplying, like capabilities. To achieve an efficient and dynamic power distribution management in smart building, a layered tree model based selection scheme algorithm is presented.

Gao et.al in [20] presents a data acquisition framework suitable for smart building and smart cities, etc. The injection of IoT in smart buildings result in large collection of data from various systems exist in Smart building such as Building automation systems, Building energy Management systems and Computer maintenance management systems. All these highly valuable data are collected and stored in a well connected web accessible databases. Thomas et.al in [22] emphasizes a new CPS namely activity-aware CPS that captures the need of resident’s daily activities and get adapted to it. The author not only explains the activity recognition algorithm, but also an activity prediction algorithm to anticipate the activities that will occur in the near future, thereby achieving Building automation.

As the size of the building varies, an effective safety management becomes an important component in smart buildings is rightly mentioned by Jiang et.al in [23]. The system is based on CPS that firstly ascertains a risk data synchronization mapping between the virtual construction and physical construction sites with the help of scene reconstruction design, data communication and processing elements. Kalluri et.al in [24] identified three important challenges in smart buildings as lack of integrated middleware, quality and fidelity of data and lack of flexible and open source middleware. To address these issues, the authors present an integrated architecture of cyber physical world capable of collecting data from sensors and connect it with cyber world using cloud computing. A centralized cloud based application written in python is used to gather streaming data and push them onto a time-series Influx database for further analysis and visualization with the help of an open source technology called Grafana. Shih et.al in [25] conducted a detailed study on design and development of CPS and IoT especially for smart buildings and cities. The study detailed on middleware as a service, distributed computing models as appropriate technology, fault tolerance, quality of data and virtual run-time environment.

IV. INTERPRETATIONS, LIMITATIONS AND FUTURE DIRECTIONS

<table>
<thead>
<tr>
<th>Technology</th>
<th>Prevailing ready to use facilities (Interpretations)</th>
<th>Improvements needed (Limitations)</th>
<th>Proposed solution approaches (Future Directions)</th>
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<tbody>
<tr>
<td>Artificial Intelligence</td>
<td>Automation achieved Highly competent in controlling systems and power usage</td>
<td>Interaction between human and buildings is yet to achieve High level of personalization is needed for robots to assist human</td>
<td>Active research is needed for providing Effective Voice recognition systems and NLP based solutions Effective space utilisation in buildings are needed to claim it as smart Building specific customization need to be explored</td>
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This survey aims at providing the information about the scope for using industry 4.0 technologies in the urge of constructing smart buildings. The role of AI, MI, BD, CC, IoT and CPS are explored carefully from the literature collected from referred journal and research articles. From the survey, it is clear that the choice of technology is not common for all types of buildings. A detailed investigation need to be obtained from the building owners/users regarding the context/purpose of using the building and based on that appropriate technology is chosen. A generic framework would be built specific to commercial building or residential building. The findings, limitations and future directions are presented in the above section. Too much of technology in one platform will increase the complexity of the smart system.

REFERENCES
7. Marcin Dryjański, Mateusz Buczkowski, Youssouf Ould-Cheikh-Mouhamedou, and Adrian Kl, 2020, Adoption of Smart Cities with a practical Smart Building implementation, IEEE Internet of Things Magazine.


