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Research Article

Augmented Reality and Mobile Technologies in Building Management Systems: A Case Study

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Abstract

Through the application augmented reality, there is an increasing number of buildings that are projected to become increasingly smarter to increase the operational efficiency of those buildings without significantly impacting the costs. This work examined the application of augmented reality in building management systems using an exploratory industry-based case study approach to examine the value of augmented reality in the business of building management. Currently, a number of companies' remedy with augmented reality already exist, however little implementation has gone beyond the pilot project phase. This may be attributed mainly to the limitations of hardware and software technologies, especially when running augmented reality applications on mobile devices. Limitations such as the need for low latency and smarter object recognition as well as the lack of standards in the development of augmented reality applications across various devices all contribute to the technology's slow adoption. This paper examines viable implementations of augmented reality in building management and presents a solution that can bring tangible benefits to the building management services sector. The architecture and technologies used in the case study are discussed as well as recommendations on the implementation and further testing of the proposed solution.

Keywords: Augmented Reality; Building Management Systems; Mobile Technologies; Intelligent Buildings; Internet of Things

Introduction

The Internet of Things (IoT) has found its way into the daily operations of many industries, including the building, facilities and energy management sectors. There is a growing need for a unified platform that can integrate a multitude of systems whilst simplifying the interface behind system architectures, programming languages and organizational protocols. Organizations are continuously looking for intelligent solutions that can drive operational efficiencies without excessive operating costs.

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Through an industry-based case study, the examination of the application of augmented reality was carried out. For the purpose of this work and to attempt to preserve the anonymity of the host company for this project, the authors use the term Company ABC to refer to the host company.

The Company ABC is a global specialist in the energy management space, offering integrated solutions to make buildings sustainable, smarter and more efficient. Company ABC's integrated building management system aims to deliver shared information between systems, providing a common interface and consolidated monitoring locations via the web to yield an improved management of energy consumption and subsequently, aiming to minimize the impact on the environment. However, due to the multifaceted nature of a building's infrastructure and the many disparate systems in a building, it can be quite a challenge to locate, receive and update detailed information about a particular asset or component. Often, it is necessary for the technicians and engineers to be physically located in the building to respond to service requests or maintenance, which leads to an inefficient use of time and resources.

Company ABC has developed software platform solutions for the management of engineering, planning and operations, asset performance and information management. Their latest addition offers an integrated management and control of a building's energy, heating, ventilations and air conditioning (HVAC), lighting and fire safety to address the elicitation and maintenance of data surrounding the infrastructure of intelligent buildings. The study explores further the application of augmented reality (AR) with the use of mobile technologies in building management systems, and investigate how AR can be used to improve the accuracy and speed of service delivery and investigate the value that it can add to existing building management solutions.
This work provides an overview of intelligent buildings and integrated building management solutions along with an examination of the literature. The project goals and aims are discussed, and subsequently a solution is proposed, presenting the tangible benefits of an AR-supported solution in an organization as well as the limitations and challenges of augmented reality application in building management systems.

Overview

According to The Impact of Control Technology, "the building sector is responsible for about 40% of energy consumption and more than 40% of the greenhouse gas emissions" (Stluka & Foslien, 2011, p 199). There is a growing interest in increasing the energy efficiency in buildings and leveraging on real-time control technologies and optimization to help tenants and building owners reduce their energy consumption. However, typical building environments are complex and heterogeneous. Buildings, which are already inherently multifaceted, are composed of complex sub-systems conventionally installed independently of each other. Sub-systems such as energy management, lighting control and security systems all have dissimilar structures and can cause problematic dependencies when integrated with each other. However, new advancements in building automation systems are addressing these aforementioned challenges.

Company ABC considers that in order to solve the heterogeneity and complexity of building environments, a "brain" should be put in place to intelligently control the systems and data points that buildings generate. Company ABC's building business aims to fill that gap by offering an integrated approach in uniting compound systems across enterprises from a single software platform. Through integration of data generated by the systems, data is translated to relevant information empowering decision makers to create solutions which will enhance the efficiencies and comfort of a building while making measurable savings.

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Continental Automated Buildings Association reports that a fully integrated system has significantly lower life cycle costs as compared to a non-integrated system as it needs less hardware drivers and devices due to the shared information throughout the system. Similarly, a full integration approach can yield approximately 82% less in annual operating and maintenance costs compared to a non-integrated system (Continental Automated Buildings Association, 2004). This further indicates that the streamlined communication of data among multiple systems due to the integration of a building's component systems is optimizing the operation and maintenance of the building environment. This integrated and smart environment has formed the basis of what we know now as Intelligent Buildings. According to Ghaffarianhoseini et al (2016), "the notion of intelligent buildings has become increasingly popular due to their potentials for deploying design initiatives and emerging technologies towards maximized occupants' comfort and well-being with sustainable design."

To efficiently monitor building environments, information needs to be generated, managed and communicated. As such, data has a large role and a ubiquitous influence on Intelligent or Smart Buildings. An intelligent building will make use of this data to trigger alarms based on a set rule or a predefined state or it can prompt a service request in a likely case that the building management system identifies a defect in the building assets. Company ABC uses a building management system package to optimize energy consumption, manage and leverage building data, and provide 24 x 7 access to information to any location. The software assists and simplifies the daily operations of building management and maintenance by setting up alarms, creating trend logs and generating reports to " facilitate the exchange of data and analysis from the energy, lighting, HVAC and fire safety systems" (Total Automation Concepts, 2017). To ensure that the building is operating at peak performance, Company ABC also employs a group of certified service technicians and service delivery managers, who conduct continuous monitoring, analyze diagnostic results and perform on-site and predictive maintenance.

Literature Review

Although research on the impact of augmented reality in the building management industry is limited, there is research on the application of augmented reality and building information modeling (BIM) to support construction work. Augmented Reality can be used to facilitate design and constructability review process on site, allowing workers to see 3D interactive models of the design. Information can also be generated based on the contextual situation of the workers to ensure that they make intelligent decisions. AR technology can be used to expedite the assembly tasks as well as simplify indoor BIM-based navigation.

According to Hugues et al (2011), augmented reality (AR) is a pioneering future trend and system that allows the injection of virtual contents into the physical world in real time to enrich and improve the user's sensory perception of reality. Augmented reality differs from virtual reality in such a way that it combines a physical or material simulation with a virtual reality overlay simulation, yielding a full immersive experience (Barsom, Graafland & Schijven 2016) whereas a virtual reality system is often characterized by a computer-generated experience. With augmented reality, an individual is able to integrate 3D objects into their usual viewing perspectives without losing the autonomy of moving objects and individuals in physical environments. Augmented reality is predicted to become the medium to communicate building information modelling (BIM) by visualizing BIM data directly into the real-world environment. AR is essentially used, as a visualization tool where any data input into it is rendered into information that makes sense for end users.

Though limited in the research of augmented reality in the building management space, there has been some research on the application of augmented reality and building information modelling to support construction projects and activities. Wang et al (2014), in their study entitled, "Integrating Augmented Reality with Building Information Modelling: Onsite construction process controlling for liquefied natural gas industry", discusses four different kinds of applications of an integrated BIM and AR in the industry, which is also believed to be applicable to the building management industry. The first application is a "walk-though functionality that can facilitate design and constructability review process right on the site." Traditionally, 3-dimensional (3D) object models would have to be drawn on 2-dimensional (2D) front designs and are stored in bulky piles on site. In order to find a specific detail, engineers and builders are required to sift through these documents and drawings making the process quite time consuming. Additionally, there exists the problem of 2D drawings being unable to exactly depict the specifications of the 3D model and can be challenging to produce in short notice or spontaneously, if required. The AR walk-through functionality can address this challenge by providing workers with a full 3D interactive model of the design to work with and examine. Workers are able to zoom in on specific details and get an overall picture of the site through augmented reality.

The second application of BIM and AR as discussed by Wang et al (2014) is an augmented reality context-aware mobile system. There is a large volume of information that goes into the construction process and often times, and the differing information is stored in various information mediums and models. "Industrialization of the construction process requires a high level of automatisation" and the industry's main challenge lies in the handling of information and integration of data and information systems (Babic, Podbreznik & Rebolj 2010). A context-based AR system can address this challenge by generating information based on the contextual situation of users and visualizing these information to provide the workers on-site with an enriched understanding of their work. Users can simply encapsulate information in a database such as BIM and have information readily available when they view a specific component in the system. Context-aware augmented reality user interfaces can display adapted information to users based on their specific situation (Grubert et al. 2016). This also provides the user with an opportunity to report a problem once they detect an error in the system.

The third application of building information modelling and augmented reality is onsite assembly. Most of the activities on site require various levels of tactile and visual guidance. Augmented reality technology can be used to improve this activity as it has the capacity to integrate informational activity with direct work, making the information more accessible and additionally more efficient. Conventionally, instructions and manuals are potentially extensive documents and those tasked to do onsite- assembly rely on these 2D drawings to assemble 3D model assets. Workers would have to not only conduct a series of physical activities but also comprehend the information from these planar drawings. The implementation of an assembly task therefore involves a large number of interchanging between physical and mental processes and yields a considerable amount of time that is irrelevant to building the actual work pieces (Zaeh et al. 2009).

Through augmented reality, workers are able to save more time and improve the quality of work by integrating the information context (i.e. installation sequence or assembly path) directly into the physical workspace. With AR based animation, workers are able to simulate the systematic sequence in a tangible scale and view the orientation, dimension, material and shapes to have an enhanced overview of the assembly process.

Augmented reality can also be used for an indoor BIM-based navigation technology or wayfinding. Wayfinding is a complicated cognitive process especially for those in a large and unfamiliar environment. Traditional wayfinding aids can be time consuming and can cause stress to an individual (Kim et al. 2015). With the aid of augmented reality, workers are able to pinpoint the exact location of a component in a site. The environment can easily be augmented with virtual arrows shown on the user's device (e.g. mobile phone) indicating the directions for the user to follow.

Given these functions, there are currently four levels of complexity and sophistication in augmented reality applications, as outlined below:

Location-based Augmented Reality

In a location-based AR, the application overlays the relevant information on top of the actual physical view in real time. It detects the current geo-location of a target and typically is embedded in a product (i.e. GPS navigation system or a mobile phone). It is mainly comprised of wireless nodes that release signals and readers that can receive those signals. Location based AR is different from marker based AR as it does not need to use a marker to trigger the display of information; rather, it makes use of GPS and simultaneous localization and mapping (SLAM) to detect the location of the user and to pinpoint the orientation of the device. This, therefore, creates a more immersive experience for the individual as it relies solely on physical proximity to trigger an action (Liddell 2017).

Marker-based Augmented Reality

In a marker-based AR, the user would have to manually scan markers such as QR codes using the AR application in order to identify assets and trigger relevant information. As a user scan a QR code, the corresponding 3D models are then retrieved and associated to their physical counterparts. A marker-based AR makes use of visual markers already embedded into the system to detect the physical objects and superimpose the virtual elements in the real world frame. "The marker tracking allows the use of a digital image to identify optical squares or markers and gauge their relative orientation to the camera itself" (Levski, 2017). In a marker-based AR, a user would have to know exactly what the application should recognize whilst obtaining camera data.

Marker-less Augmented Reality

In contrast to a marker-based AR, a marker-less augmented reality application recognizes images that are not provided to the application beforehand. The AR app creates a 3-dimensional representation of its environment adapting in real time to the user's gaze and physical environment. Assets are detected automatically and enhanced with virtual data. This essentially eliminates the need for 3-dimensional object tracking systems and allows the use of any or all parts of the real world environment as the target or base for the placement of superimposed virtual elements. This application is more difficult to implement, as the algorithm built in the application must be able to recognize patterns, shapes, colors and other features without providing these images in the database when developing the application.

Enterprise Augmented Reality

The enterprise AR is perhaps the least mature level in augmented reality application, as it requires the full integration of the Internet of Things and back-end systems. This also requires the application to fully understand the workflow and processes in a site and improve procedures through gesture analysis and workers' feedback.

These augmented reality levels heavily depend on the maturity of the technology available. Software manufacturers will have to be quick in developing relevant technical solutions and hardware manufacturers would have to ensure that the devices' computing power, memory capacity and battery life are sufficient to make augmented reality models feasible for day-to-day use. However, a parameter that is easily overlooked is the demand for the application. Both organizations and users must be able to generate an actual demand for the application and recognize the saving potential of augmented reality in the building management space.

Project Goals

When a service request or maintenance work is triggered, a service technician is needed to visit the site location to investigate and obtain information about the raised work request. Although this is currently working for the organization, the situation is not optimal. Projects and service engineers within Company ABC's project and service engineers often maintain multiple sites and subsequently considerable time is lost due to travelling from site to site. As Company ABC mainly operates in the commercial space, commercial buildings have assets that are not easily accessible to project and service engineers which may pose as a problem when trying to access them. Workers would also require accurate information including the specification of the building resources and the state of the building's infrastructure and assets in order to conduct the service repair or maintenance work. This information is often stored in separate repositories.

The aims of the project were to design and integrate solution using augmented reality along with emerging and mobile technologies to be integrated into Company ABC's building management system; and to also examine the value that may be added to the organization through the application of augmented reality with the mobile technologies.

Methodology

The project used an exploratory case study method with one of the authors located in and working alongside the service and sales team members employed in Company ABC. Pickard (2013) indicates that the purpose of case studies is to provide an intensive analysis in a specific context to provide insight into real-life situations. Case studies provide the pathway to explore and understand complex issues in an environment. Being immersed in Company ABC, provided the avenue to identify problems and opportunities in current building management systems and the methodology used to develop a viable solution; and allowed a deeper understanding of the market needs and the different challenges project and service engineers face in their day-to-day responsibilities.

Following an examination of the pain points with the company's projects and service delivery team, views were sought from industry experts on the possible integration of augmented reality with building management systems. In addition, through utilizing the organization's building operation software, the value of an integrated platform could be examined for the benefits of both Company ABC and its customers.

After reviewing the existing AR frameworks and architecture, a solution was designed focusing on the interoperability between different modules and components, ease of maintenance work, and improving the management and handling of assets and service requests.

Solution Design

The solution involves the development of a marker-based augmented reality application, making use of natural markers instead of artificial ones. Artificial markers, like QR codes are quite distinct and have visible patterns or dimensions. However, artificial markers need to be installed all over the site to ensure that they are recognized in real-time. Natural markers, such as device tags and signs, are readily available and do not need additional instalment. These natural markers can be used in conjunction with building information modelling to support service delivery teams in conducting their service requests and maintenance work. The solution proposes the use of mobile devices instead of headsets or glasses as an interface for the augmented reality software. Smartphones are currently used by the project and service engineers and as such, can simply be leveraged as the platform for object recognition and graphics overlay.

Most augmented reality environments are based on the open source software development kit (SDK) ARToolKIT, which allows developers to build augmented reality applications. It makes use of video tracking to compute the real time camera position and orientation relative to the natural markers in real time. When the real camera position has been identified, a virtual camera can then be positioned at the same point to overlay 3-dimensional computer graphic models on the marker. Since the conception of ARToolKit, similar AR libraries have been developed such as HandyAR, AndAR, Atomic Web Authoring Tool, and Vuforia (Qualcomm AR) to cater for different needs.

For this project, Vuforia SDK was recommended for the AR software building. It does not only support a variety of devices such as Android and iOS and digital eyewear, but it also has an advanced image recognition engine. It supports robust 2D image based tracking and a 3D object based tracking which is ideal in displaying information for both planar drawings and actual assets on site. Similarly, the development of Vuforia Studio has allowed organizations to work on 3D asset models without requiring deep programming or AR technology expertise. In creating targets, the Vuforia Capture App can be used to scan an image, object or environment to create target objects, and the Vuforia Target Manager can be used to create and manage the target databases for use on cloud or devices. Subsequently, Vuforia has a Cloud Recognition Service that allows the use of cloud-based target database and Web Services, which can be integrated with existing content management systems and enable the management of cloud-based target databases using RESTful APIs.

As the proposed solution must also be able to integrate with the organization's building management system (BMS) by obtaining instantaneous data from physical and virtual sensors, an event condition occurs, that triggeri an alarm in the BMS, and a maintenance or work order is then requested in the Service Request Management System. The system would include the details of the work order such as the name of the asset or equipment, where it is located in the building, its urgency, and severity. It also contains the instruction manuals and materials used in the equipment to ensure that the service team has the entire work order information ready in a single interface. Subsequently, these details are sent to the augmented reality application. From this stage, pre-defined natural markers such as ID tags or bar codes next or on the equipment are recognized on site. The project or service engineer then uses the camera on their mobile device/phone to capture these natural markers and relevant information from the Service Request Management System. The user is also able to update the work order in his mobile device by reporting the problem and/or changing the information on the equipment.

The proposed solution comprise of the following components:

Data Collection

The data collection system in the solution captures real-time data from the building management systems, which is integrated with the EcoStruxure Building Operation software. It includes raw data and metrics to be passed on to the Service Request Management system or used for third party analytic tools and visualization dashboard.

Service Request Management

In the Service Request Management system, a work order or maintenance repair is requested. The system amasses the necessary information regarding the work order on a single platform. The information includes the equipment to be investigated, past and current condition of the equipment, and the different work processes needed to perform the service request.

Augmented Reality Application

The augmented reality application is accessed through the user's mobile device and will be used to locate and scan natural markers. The information coming from the Service Request Management System is displayed on the application and the technician or engineer will be able to access and customize the view whilst conducting the service request. The AR application also visualizes the warnings and alarms from the Building Management System and allows the user to interact with them.

Discussion

Although it is still in its infancy augmented reality, technology is expanding across multiple organizations and industries. It has the opportunity to provide improvements to previously overlooked difficulties and can deliver solutions to enhance workflows and processes.

An important role of the augmented reality is its ability to simplify various assets that often require a steep learning curve and visualize it through intuitive experiences. One of the most common uses of the augmented reality in the field service, manufacturing, and construction environments is the overlay of systematic instructions on certain machine equipment when performing a maintenance or service request. This visually guides the worker through their job and can drastically improve a worker's productivity and efficiency on a range of tasks that are used for the first time, even without prior training. At ARise 2015, Paul Davies conducted a study to illustrate the differences in performance when complicated tasks are performed following 2-dimensional work instructions versus augmented reality. The results show that zero errors on average per person were made using augmented reality for first time assembly tasks, and that AR-supported participants completed tasks for the first time faster than those who followed instructions on a desktop computer and a mobile tablet. Furthermore, there was a 90% improvement in first time quality between desktop and augmented reality modes with AR reducing time to build by around 30% (Babb 2015).

A significant often-overlooked challenge on sites is the worker's safety. In the daily operations of machines and facilities, organizations must adopt an array of measures and safety equipment to safeguard the safety of the personnel. However, scheduled and emergency maintenance and service work often require the work to be done on sites with demanding conditions (i.e. low visibility and mobility). Augmented reality can reduce the time needed to perform the maintenance work and improve the safety of the worker by minimizing the room for errors. For example, workers can view the 3D models of the assets in real time and see relevant and actionable data on the components such as hazards identification, and its history and present condition. Potential hazards and critical emergency information can also be emphasized in the AR interface so that the workers are aware of on-site hazards and remedies. With augmented reality, the safety processes on site are able to adapt to real time changes in workplace conditions and therefore empower workers to reduce risks and improve their situational awareness.

Augmented reality can also provide a new, more streamlined format for integrating information that further improve the worker's knowledge. Using augmented reality technology eliminates the need to transfer documents and technical documents to the relevant sites; where, at present, project and service teams need to flip through pages, either paper or online, to find and identify relevant information. Subsequently, this information would have to be transferred on site where the task has to be conducted, and requires the worker to interpret the technical documentation and align the planar drawing and existing graphics with its physical counterpart. In an AR-supported environment, the search and transformation would not be necessary as the information is already presented on site and in real time. Augmented reality technology allows the worker to adjust information based on the current context.

AR technology can significantly reduce costs by increasing worker's productivity and equipment efficiency, reduce waste caused by redesigns or human error, and lowering the operational overhead, leading to an increase in cost savings. The use of interactive maintenance and technical documentation can additionally reduce costs associated to training workers as well as the service team's average maintenance time. The augmented reality application can also be programmed to provide visual cues to the service team in a likely case that a problem or defect arises, allowing the actual problem to be viewed before disassembling the equipment. By allowing the asset to provide a visual image via augmented reality to the worker, AR is able to deliver significant time and cost savings during diagnosis and repair.

Improved on-site data quality, integration of workflow information and minimization of errors are the main driving forces in the adoption of augmented reality in the building management sector. With augmented reality, workers are able to conduct a comprehensive simulation of a service request without shutting down a system or consuming a material. The project and service team in an AR-supported environment are then able to define an optimal workflow, which may be implemented in the system, itself, leading to a significant improvement in tasks being done more safely and efficiently.

Although, there are already a number of companies experimenting the augmented reality, not a lot of these implementations go beyond the pilot projects. For instance, in the 2017 SPAR 3D conference, McCarthy, a commercial construction firm has demonstrated an excellent application of augmented reality in the industry (Chaplais 2016). With solely a handset and handheld controllers, an audience member with no mixed reality experience was able to move things around the virtual environment. This not only proves how easy it is for workers on site to use AR to inspect assets and access maintenance reports but also how mixed reality can be easily visualized on handheld devices. However, McCarthy's application still appears to be on trial. According to Gather's technology hype cycle (Stamford, 2015), augmented reality is in its trough of disillusionment and its mainstream implementation and adoption will not occur for 5 to 10 years.

Along its development path, augmented reality technology has met some challenges and limitations that contribute to its slow adoption. For one, developers and designers of this technology must be able to find ways in which they can render useful digital data into meaningful graphics that can be scaled to fit visual field. This is especially true with mobile phones as AR applications must be able to work with the limitations of not only the phone's screen display but also with its processing power, memory storage and capacity. Executing a fully featured AR application with the camera will cause a substantial strain on the phone's battery (Kolsch et al. 2006). Likewise, a mobile phone's camera quality must also be factored in, as the camera must be able to scan objects on site regardless of the lighting and color fidelity. Another factor to consider is the accuracy of the global positioning system (GPS). Currently, the GPS is only accurate within 30 feet and does not work well indoors.

Nevertheless, it's believed that there will be significant improvement in both the hardware and software components of augmented reality that can drive the technology's growth and adoption. In the author's proposed solution, it's recommend to develop a marker-based augmented reality that makes use of natural markers such as device tags and bar codes on the equipment. The solution design also recommends the use of mobile devices for the pilot project to lower the investment costs and because projects and service engineers already carry their mobile phones with them when going on site visits. The Vuforia Software Development Kit (SDK) will be used to build the AR software as it can support both Android and iOS and has an advanced image recognition engine which can be useful in sites where there is poor lighting and color fidelity. The proposed solution also makes use of cloud-based target databases to store marker images so that the phone's memory capacity is not being strained when executing the application. The three components of the proposed solution involve a data collection where the system captures real-time data from SE's building management system. The service request management captures work order or service requests and collects all the information to be visualised in the AR application. Lastly, the AR application will be accessed through the mobile device and will be used to locate and scan natural markers. Both of the information that are coming from the data collection and service request management will be encapsulated and displayed in the AR interface to assist the worker in conducting the service request.

Due to the limitation of augmented reality in hardware – especially in smaller screens, clumsy or inaccurate interaction can happen. Users might be able to accidentally trigger unintended actions or press two buttons on the screen at the same time. Input capabilities must therefore be further developed to ensure that 3-dimensional interaction is made more precise and accurate.

In order for augmented reality to be useful, it needs a relatively low latency – AR applications must be able to respond quickly as the user scans objects across the site to guarantee an immersive and real experience. This means that the technology should be built with the ability to track where the user is, where he is pointing at and how it is moving and then determine where the virtual content should be superimposed over the view of the physical environment – all in a span of milliseconds. Hence, embedded motion sensors and cameras must be able to integrate and work together to safeguard the stability of the virtual interface. Moreover, low-latency tracking makes use of high- end sensors, which entail a high volume of computational resources. However, because of the current limitations of mobile phones, it would not be easy to develop new tracking algorithms in smart phones. Gotow et al. (2010) stated that the noise in geomagnetic heading values often cause jitter in mobile screens when presenting information. AR developers must also ensure that information is rendered accurately and superimposed with the right elements in the physical environment. Erroneously aligned overlays can provide disingenuous and ambiguous information and can lead to poor user experiences. To address this, graphics libraries (i.e. OpenGL) can be used on mobile devices to render 3D models in real time but again, requires the integration of low-level services provided in the APIs of mobile operating systems.

As mentioned in the previous sections, augmented reality can be used to visualize technical content. Written documents such as instruction manuals, and 2D designs will be replaced with 3D objects and models depicting components, activities and navigations. However, creating this technical documentation requires a different kind of skillset and currently, there is only limited training offered around the creation and development of AR content. Similarly, tools used to create this documents are still in its infancy stage, causing most augmented reality developers to use design tools that are not necessarily built for creating augmented content.

Conclusion

Intelligent buildings based on IoT concepts and emerging technologies are projected to evolve in the next 5-10 years. There is a growing interest in increasing the energy efficiency of buildings and leveraging on real-time control technologies and optimization. In recent years, research has shown that a fully integrated building management system has significantly lower life cycle costs compared to a non-integrated system. With organizations looking for solutions to make buildings smarter and more efficient, the integration of AR applications with building management systems would lead to driving operational efficiencies.

Given the numerous benefits and applications of augmented reality in the industry, the adoption rate of augmented reality is growing at a very slow pace. This may be attributed to the limitations in hardware technology. Digital data must be rendered and scaled to fit the screen display on mobile phones and tablets. Difficulties may also be experienced where user's fingers may make it hard to have an accurate 3D interaction within the application due to size. A low latency is also essential as AR heavily depends on the ability of the application to quickly and accurately super impose elements into the physical environment.

While the application of AR and mobile technologies in building management systems is still in early stages, there already are expected benefits that can be delivered. This includes its ability to increase the productivity and efficiency of workers by visualizing models through interactive experiences; and therefore, revolutionizing how onsite training is conducted. AR also reduces the time required to perform maintenance work while improving worker safety and minimizing the room for error. AR provides a more streamlined format to store and integrate the employee's daily task information and documentation. Technical documentation in the form of 3D models and step-by-step guides can simply be displayed through AR ensuring the information is readily available when and where needed.

Essentially, the further development of augmented reality in the building management sector will heavily depend on two parameters. Firstly, major players in the industry should be able to recognize the valuable benefits and saving potential of the technology when successfully developed and implemented. Organizations must be able to generate an actual demand for ethe technology so both software and hardware manufacturers can be quick in coming up with pertinent technical solutions. Likewise, organizations must be aware that the adoption of augmented reality requires a substantial investment. On the other hand, the hardware components in augmented reality and mobile technologies need significant improvement to ensure that the AR applications can be used in the project and service teams' daily operations. Nevertheless, until these limitations are resolved, the industry will not be able to see how augmented reality can make more intelligent and more efficient building management systems

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