Optical Internet-of-Things

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ABSTRACT

Internet-of-Light (IoL) is introduced as a secure and intelligent network applied to services as manufacturing, transportation, health, lighting, communications, imaging, sensing and navigation. The most compelling story of how IoL will transform our world is the birth of a new enterprise lighting network.

Keywords: Internet-of-Things, Light Emitting Diode (LED), Visible light communication (VLC) technology, location-based services, Internet-of-Light, enterprise lighting network, Artificial intelligence

1. INTRODUCTION

With the increasing popularity of Internet-of-Things (IoT) supplied over the backbone network, services such as: web browsing, video conferencing and video on demand, it is for sure only a matter of time before users will demand higher bandwidth mobile access. Advances in displays, battery technology and processing power have also made it possible for users to afford and carry around laptops, notebooks and smartphones. The prospects for the delivery of all associated services to these users is, however, crucially dependent on the development of low cost physical layer delivery mechanisms. Market needs to consolidate the data into one single handset.

The IoT (Internet-of-Things) is a modern-day buzzword with lofty expectations to have a profound impact on society. However, what is it, how will we use it and what will that impact be? Is it exciting or will it be frightening? Will it be helpful? Who will be the winners and who will be the losers? These are important questions, especially when you consider that IoT may have as great an impact on society as computers and the Internet have had. Maybe even more. In the Internet of Things, connectivity to people and things comes from Earth-bound wired and wireless networks. However, fewer technologists know about the evolving Internet-of-Space (IoS), where connectivity comes from space-based satellites and—in the near future—lower altitude airborne platforms based on drones and even balloons.

This paper elaborates on a novel idea called; “Internet-of-Light”. It can address the needs of both IoT and IoS. It is very secure at physical layer and can be applied to many real and necessary service areas; e.g., manufacturing, transportation, health, communications, sensing and navigation, to name a few, that are all essential technologies for our nation. The most compelling story of how Internet-of-Light will transform our world is the one still being written: the future of lighting, communications, sensing and the birth of a new enterprise lighting network [1].

2. ARTIFICIAL INTELLIGENCE

The IoT is typically a set of “things” connected via the cloud (Internet) to a server that stores and analyzes data (trends, alerts, etc.) and then communicates with a user via an application running on a computer, tablet or a smartphone. However, it is not the “things connected to the internet” that create value, it is the "knowledge" conveyed through use of Artificial Intelligence (AI) and Machine Learning. The latter is a modern term for the good old "Pattern Recognition" in signal processing. In AI, an expert system is a computer system that emulates the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning through bodies of knowledge, represented mainly as if–then rules rather than through conventional procedural code. The first expert systems were created in the 1970s and then proliferated in the 1980s. An expert system is divided into two subsystems: the inference engine and the knowledge base. The knowledge base represents facts and rules. The inference engine applies the rules to the known facts to deduce new facts.

The term "IoT" is somewhat confusing and deserves some clarification. To many people IoT implies "mobility" which brings "wireless" into the picture, whereas in reality, many applications, like in smart home services, do not involve mobility and not even wireless. Actually, IoT was used before the advent of Internet, using telephone lines in a wired network. When considered from this perspective – as a service that gathers, analyzes and transmits data – the IoT has been in existence for years or even decades. For example, in the early days of wireless telephones (long before the term IoT started floating around), vending machines “called” a dispatch center when running out of a product, transmitting full inventory information at the same moment. The dispatcher then sent a refill order for that machine. Entirely more efficient than some person in a truck just driving around to every hotel or office building and manually checking each vending machine. Another “old” IoT application was the ordinary home or building security system, with a set of motion sensors, wired to a patch panel, and from there connected to a phone line and an alarm service center. If the house is armed and a sensor is triggered, the alarm service center calls the house, the neighbors or the police. Note that, this pure IoT application (in the sense of Internet of Services) is also fully wired. The IoT does not need to be wireless. This particular IoT application existed before the Internet, making the ADT Security Services one of the older IoT companies existing today. The word "Things" in the "Internet-of-Things" confuses the true objective behind this concept. May be the term "Internet-of-Services" is a better term to use. For a better understanding of the subject, the readers may check out Figures-1 and 2 - below.

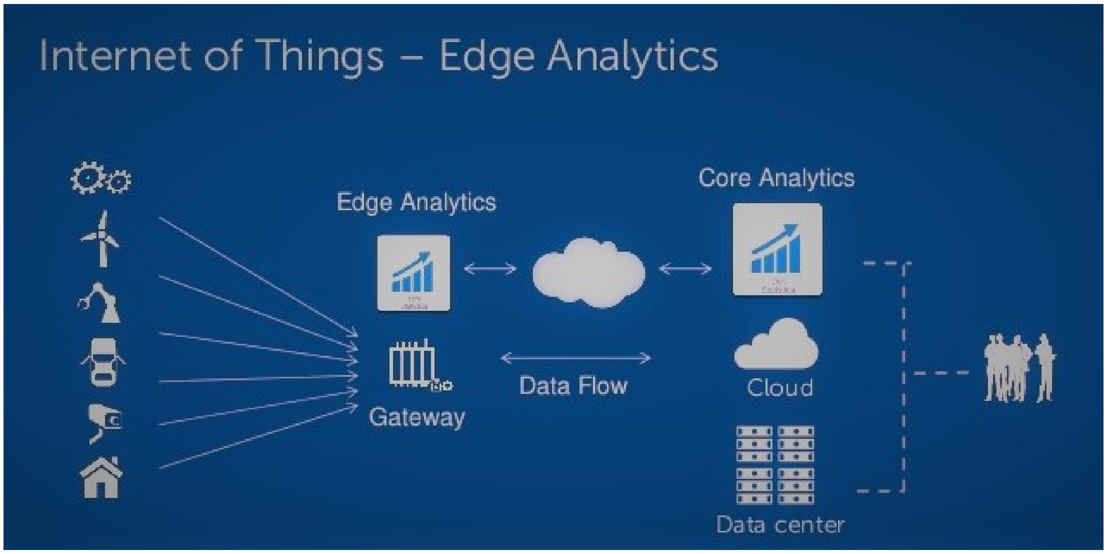

Figure 1 Internet-of-Things Idea

Under data value analysis to action, API is the acronym for Application Programming Interface, which is a software intermediary that allows two applications to talk to one another.
To summarize, a “thing” is any object with embedded electronics that can transfer data over a network — without any human involvement. Wearable devices, environmental sensors, machinery in factories, components in a vehicle or devices in homes and buildings can all be connected to deliver insights and drive transformation. So imagine if you had smart devices in your home, your car, your workplace ─ or even

on yourself, IoT can make life easier and reinvent the way we interact with the physical world. The number of internet-enabled data devices is rapidly outpacing the number of humans on the planet. By 2020, it is estimated that there will be over 50 billion connected products. Gartner, Inc. forecasts that the enterprise and automotive Internet of Things (https://www.gartner.com/smarterwithgartner/lessons-from-iot-early-adopters/) (IoT) market-will grow to 5.8 billion endpoints in 2020, a 21% increase from 2019. We explore the potential of the IoT by asking not only how to create connected products but how to connect them in a *meaningful* way, in order to improve people's lives, bring people together, in addition, enrich human-to-human interaction through device-to-device connections.

Human resource departments to assist in understanding how employees feel about their work, The Wall Street Journal reports, are using artificial intelligence (AI). AI does a better job than human at gauging worker emotion and satisfaction through the language used in surveys, according to the research. At First Horizon National, a bank in Memphis, a team of six human resource personnel would work for three months to understand the bank's 3,500 employee surveys. Managers would then spend another five months adjusting policy in accordance with the data. AI gave the company almost instant results. AI can help bosses build better workplaces.

The IoT brings together people, processes, data and things to make networked connections more relevant and valuable than ever before. According to a Cisco study published in 2013 [2], the IoT will Create $14.4 Trillion of Value at Stake for Companies and Industries globally over the next decade. The value at stake is the potential bottom-line value that can be created, or that will migrate among private-sector companies and industries, based on their ability to harness IoT over the next few years.

To address the bit rate limitation problems of current wireless systems, researchers examine the concept of adaptive rate delivery of future mobile / portable smart services. Examples of physical layer technologies are Cellular, Wireless LANs, and Optical Wireless (OW) for the future Smart High-Bandwidth Islands, such as; classrooms, hotels, homes, shopping malls, airports, train stations, planes, spacecraft, etc. Furthermore, demands by the communications industry for greater and greater bandwidth push the capability of conventional wireless technology. Optical systems and networks offer a far greater bandwidth. This means new devices and systems have to be developed. Semiconductor Light Emitting Diode (LED) is considered the future primary lighting source for buildings, automobiles and aircrafts. LED provides higher energy efficiency compared to incandescent and fluorescent light sources and it is already playing a major role in the global reduction of carbon dioxide emissions, because of the significant energy savings. Lasers are also under investigation for similar applications. These core devices have the potential to revolutionize how we use light, including not only for illumination, but as well; for communications, sensing, navigation, positioning, surveillance, and imaging.

As we step further into the 21st century, the demand for sustainable energy-efficient technology grows higher. The important area of electric lighting, currently dominated by decades-old incandescent and fluorescent sources, is being taken over by white light emitting diodes, which are solid-state devices with much greater energy savings. Replacement of current inefficient lighting by these LEDs will result in reduction of global carbon dioxide emissions, a major cause of global warming, among other things. White LEDs hold the potential, in the field of photonics, to be as transformational as the transistor was in electronics. This core device has the potential to revolutionize how we use light, including not only for illumination, but also for communications, sensing, navigation, imaging, and many more applications.

In [3], we highlight some of the potentials. Wireless communications by infrared (IR) or visible light or ultraviolet light is inherently secure, since it is usually confined within an enclosure. It offers no interference to existing RF sensing or communication infrastructure. It is unregulated worldwide unlike RF spectrum, and small devices can be manufactured that are suitable for miniaturized sensors.

Figure 2 Internet-of-Things from Connecting Devices to Creating Human Value.

Visible light communication (VLC) technology is one of the advanced optical wireless communication technologies. Indoor networking and location-based services are the only applications that are quite penetrated in the market [4]. Products for other applications are expected to hit the market soon. Prototypes for underwater communication are available at present. Japan sampled the intelligent traffic management systems with VLC technology and expected to bring it in the mainstream. VLC can be implemented as a complement to the existing wireless networking technologies like Wi-Fi and 5G etc . VLC is expected to penetrate in the future applications like Machine-to-Machine (M2M) communications, smart cities, wireless sensor networks, ubiquitous computing etc. in the next five years. In 2010, VLC systems were able to achieve data rates of 500 Mbps for a short range of 5 meter. With the ongoing R&D, some research institutes were able to achieve transmission rates of ~ 1 Gbps for longer-range communications. Research centers and companies are looking forward to achieve Gigabit network with VLC technology. See Figure-3 below.

Consider the area of Smart Home Networking, when every home will be illuminated with bright visible LED light that can also be considered as an extremely high-frequency communications carrier signal. We are entering a new era of global connectivity. The expectation from consumers for not only ubiquitous but also seamless data analytics (knowledge data), data (digital information, spam included), voice, video services presents a significant challenge for today’s telecommunications networks.

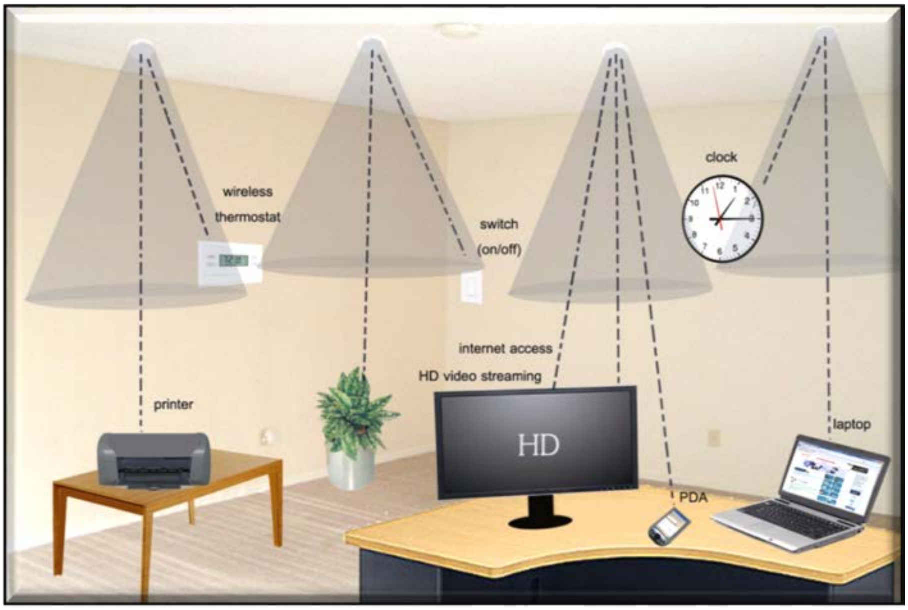

Figure 3 Local optical wireless communications using light.

Sensor networks (as in Figur-4) are also increasingly being used for monitoring and controlling vital operations in industries, hospitals, and military installations and vehicles. Current research trends concentrate on Radio Frequency (RF) technology for sensor communications. However, OW communications or Visible Light Communications (VLC) can offer a much higher data rate or higher reuse factor.

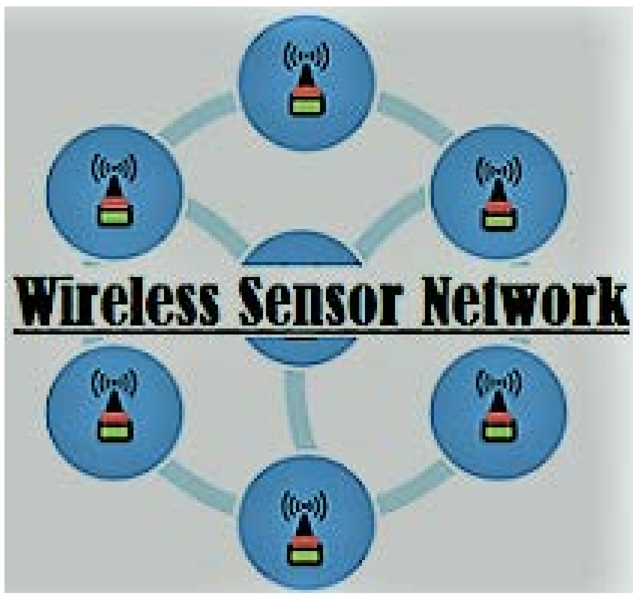

Figure 4 Wireless Sensor Networks

In addition, a novel idea coined; "Internet-of-Light" is being introduced, using light bulbs with IPV6 addresses that are available on the market now. Each bulb adds a new node to the network and it can address the needs of IoT. It is extremely secure at physical layer and can be applied to many real and necessary service areas; e.g.: manufacturing (as seen in Figure-5), transportation, healthcare, communications, sensing and navigation, to name a few. These are all essential service areas.

The most compelling story of how Internet-of-Light (IoL) will transform our world is the one still being written: the future of lighting, communications, sensing, navigation and the birth of a new enterprise lighting network [1].

Figure 5 Manufacturing by Robot Arms using the Internet-of-Light (IoL) Concept

3. INTERNET-OF-LIGHT

The Internet of Things is booming because of the large number of applications and the benefit for users. Smartphones can be used to shop online, check in for a flight or find your way around an unfamiliar city. Electricity meters automatically send energy consumption data; traffic lights, washing machines, cars and trains all give early warnings that they need servicing, and pc boards in factories tell assembly robots which components they should pick.

However, quantity brings complexity. The problem is already obvious – just look at any modern office: in addition to smoke detectors and thermostats, there are often numerous presence sensors from different manufacturers for the different building services. One ensures that the light is only switched on if there is someone in the room. Another is part of the security system, a third turns down the heating and air conditioning when the last person leaves the room, and perhaps a fourth is there to control the window blinds.

Simplification is what is needed. How can the level of complexity best be reduced, how can communication among the devices be harmonized? Are there no existing infrastructure systems to which the Internet of Things can simply be “docked”? In fact, there are. Wherever there are people, whether indoors or out on the streets, there is artificial light. In many of these luminaires, there is still plenty of space for one or other digital sensor or microchip – after all, digital electronics is necessary for modern LEDs.
What's more, since the luminaires need electricity the power supply is already integrated, so to speak. No one need worry any longer about cabling the individual sensors or changing batteries, which they would otherwise have to do every year or two or even more often – which in large buildings means a lot of work. What's more, luminaires are mostly installed on walls or ceilings and therefore in the best places for including sensors. In addition, communication with them and connection to the access points for the internet can be either wireless or via the data cabling, that is already in place anyway.

In short, the existing infrastructure for light is the ideal basis for the Internet of Things. Alternatively, to put it another way, the "Internet of Light" is the most powerful instrument for developing the Internet of Things into the useful tool that it can be in the future.

Here are some examples: A single presence sensor integrated out of sight in a luminaire is sufficient for detecting whether an office is occupied or not. This data is then stored in the Cloud – in other words on an Internet or intranet server – evaluated and forwarded to the HVAC systems, window blinds, security management system and of course to the lighting control system.

It can also be used for room management, i.e. to determine how well meeting rooms, offices or communal areas are used. Building operators can use this data to optimize the usage of the building and make considerable savings in costs.

If there are presence sensors in a large number of luminaires then the data can be evaluated in much finer detail, for example to optimize the lighting and air conditioning for each individual desk in an office. This principle also applies outside the office environment of course. For example, presence sensors in car park lights or streetlights can indicate where there is a free parking space, pass this information ensures that the free space is indicated by some visual means, such as green light.

Indoor navigation will also be possible by using "beacons", small Bluetooth transmitters, in the luminaires. With the aid of these radio transmitters, anyone with an appropriate smartphone app will be able to pinpoint their location to within a few meters – ideal for finding your way around shopping centers, hospitals or airports, or even just for finding a particular product in a large store. Unlike with previous systems the beacons would no longer have to be installed separately or set up individually because of lack of a network, nor would batteries have to be regularly replaced. Indoor localization also finds its significant application in manufacturing to facilitate using robots [4]. As artificial intelligent has been an emerging technique in recent years, using robots to replace human beings is an interest shared by some industry. In this way, production is increased, information of producing process is secured and some operations harmful for human involvement can be accomplished, safely. In order to obtain the location of a robot, a precise localization system is indispensable.

There is still significant room for innovation and an upside in the lighting industry. It can come from embracing the IoT future, including the continued development of new lighting form factors and new optics capable of efficient dynamic color mixing and light pattern shaping. By working closely with IoT, IT, and lighting design software tool developers, the lighting community (designers and manufacturers) can help shape the future of the connected lighting industry.

Perhaps one of the best opportunities for lighting companies to benefit from an IoT future is to own the sensors and explore ways to make the light emission from the fixture an integral part of a luminaire's sensory capabilities. Building off of daylight sensors incorporated into luminaires, there are new ways to use reflected light sensing of digitized illumination to perform highly accurate occupancy tracking and even generate pose-detection (e.g., standing, sitting, fallen) data. With improved lighting software design tools that take into account the spectral reflectance of a space's surfaces, compensation for glare, and ocular light dose for human health and wellbeing, better lighting spectral power distributions could be calculated more accurately than using other non-light based techniques. When the lighting system can cost effectively sense its environment (ideally using privacy-preserving low-cost color and time-of-flight measurements), lighting becomes an integral and indispensable part of any lighting IoT solution.

Besides ubiquity, vantage point, and power, the lighting industry can generate invaluable lighting based data and information not only for lighting control systems but also for other IoT connected systems in building management, healthcare operations, communications, and even horticulture. By making lighting enabled sensing a requirement for IoT system operation, IoT solutions will need to embrace lighting system design and connectivity for maximum societal benefit. However, if the lighting industry gives up the sockets (and poles) and sensors (and data) to other enterprises outside of the lighting industry, a significant market opportunity will have been missed, and lighting will increasingly become a commodity non-smart plug-in to someone else's IoT connected business future.

IoT extends the Internet Protocol (IP) communication to billions of resource-constrained endpoints, such as intelligent luminaires and sensors, reaching into the physical world.

Endpoints are typically connected into resource-constrained access networks, with low power, low bitrate asymmetric links and limited group communication primitives. As a network, IoT connects uniquely identifiable things to ‘regular’ internet services and fast networks. Embracing IoT in lighting systems creates new opportunities and value propositions. IoT is now maturing, and it is economically feasible to connect each luminaire to the internet. The transformation from traditional lighting to Solid State Lighting (SSL) makes it easier to convert light points to IP end-nodes. This presents an excellent opportunity to establish the Internet of Lights (IoL), e.g. an advanced lighting system with IoT at its core.

A transition towards IoT has several benefits as it enables using the network infrastructure in the building for controlling and powering the lighting systems rather than using a dedicated lighting network. Having IP connectivity to all light points enables flexibility and interoperability with other systems such as Building Automation Systems (BAS), smart grids and cloud services.
IoL enables the transition from command-oriented lighting control to service-oriented lighting control and, as a result, can bring in a large variety of new services, create new ecosystems, stimulate investments and innovations and benefits from global developments in protocols and tools. For example, sharing building occupancy data collected by presence detectors used for lighting controls with BAS for air conditioning or with cloud for data analytics opens up new possibilities and services. Additionally, incorporating IoL can lead to more efficient use of a building and even help to achieve certifications such as BREEAM (the world’s leading sustainability assessment method for master planning projects, infrastructure and buildings) or LEED (the green building rating system) by increasing a building performance rating and reducing its carbon footprint.

As a first step towards creating an IoL standard that is open, IP-based, extensible, interoperable and secure, the European Union Horizon 2020 project OpenAIS has been set up with key players from the lighting industry and IoT. One of the key outcomes of the OpenAIS project is to develop an IoL architecture with novel solutions for network connectivity and security that can later be standardized [5]. The IoL architecture is being developed as a reference architecture that will include a template for specifying concrete system architectures. It foresees that the lighting systems, as well as the building management systems, will converge to an all-IP-based configuration, with IoT concepts at the heart of the new lighting system architectures. The key objectives of the OpenAIS reference architecture are; Define an open architecture for lighting systems with standardized open APIs, Make the system interoperable with BAS, cloud services and other systems, Increase the building value and reduce the carbon footprint by combining IoT, LED technology and smart grids, and Easy to specify, buy, install, maintain and use IoL systems for all stakeholders in the value chain. Given the benefits of moving towards IoT, extending the existing lighting standards to bring in such benefits is an option.

However, the introduction of IoL can bring new challenges, listed below.

Performance: Moving away from today’s dedicated lighting network to an IT network with cloud-based communication of IoT raises several questions. Ensuring reliability and guaranteed performance of dedicated lighting systems in an internet-connected luminaires’ world is the key issue to solve.

Security: With the IoL, the system becomes more vulnerable to attackers and attack vectors. Making the system secure while opening it to the internet is a central issue in all IoT systems. Careful monitoring of security vulnerabilities and updating to the latest security provisions will be needed. Methods to detect security violations, to prevent leaking of sensitive information and to recover from an attack without huge overheads are core concerns in the security design.

Privacy: Data collection and analytics enabled by IoT can be beneficial. However, revealing information about individual users such as occupancy patterns, motion tracks and usage profile can lead to privacy issues. The system must support privacy requirements like the right to delete data or to be forgotten. Measures need to be taken to prevent privacy violation while enabling data sharing.

Energy: The transition to SSL provides huge savings when compared to the conventional fluorescent or incandescent lighting. However, in a modern lighting system, the control logic, power distribution logic and interface logic consume additional power. The increased standby power consumption of IP devices should not jeopardize the overall energy efficiency brought by the SSL.

Finally, intelligent control algorithms should be employed to reduce the energy usage.

4. CONCLUSIONS

The Internet-of-Things is the next industrial revolution. Experts are convinced that lighting will play a decisive role in the Internet of Things (IoT). In this article, we explained how the lighting industry might benefit from IoT by moving from the traditional closed and proprietary systems to secure, extensible, interoperable and service-oriented systems. With an Internet-of- Light architecture, OpenAIS, designed to address the challenges while making this transition. The vision of the OpenAIS project is to create an open ecosystem to enable a wider community to deliver the smartness of light. The OpenAIS project focuses on the professional domain of offices and public buildings as a first area of validation of its vision and objectives. The transition towards IoT enables using/sharing the network infrastructure in the building instead of employing a dedicated network for each building services. Ensuring reliability and guaranteed performance of dedicated lighting networks in shared networks will be a challenge. The security and privacy of IoL is an issue not fully resolved. Careful monitoring of security vulnerabilities and updating to the latest security provisions are needed. To ensure privacy, strong policies and their enforcement for data storage and handling are needed. A careful study on the impact of IoL on various stakeholders and the changes it brings in to the lighting value chain and building sector need to be carefully analyzed.

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