An Investigation on the Adoption of the Internet of Things (IoT) in Sri Lankan Construction Industry

ABSTRACT

The world is witnessing the dawn of the Fourth Industrial Revolution known as Industry 4.0, where the ICT-fuelled digital economy is taking off exponentially. In such a context, the pervasiveness of the Internet identified as the Internet of Things (IoT) is a revolutionary way of procuring goods and services. IoT refers to scenarios where network connectivity and computing capability extend to objects, sensors, and everyday items not generally considered as computers while allowing them to interact among each other with the least involvement of humans. Application of IoT has already extended to the sectors such as manufacturing, transportation, energy, retail, smart cities, healthcare and buildings to significantly improve the quality of life by increasing efficiency, productivity, profitability, and innovation. Meanwhile, the construction industry is still suffering from complexity and bottlenecks, where IoT has aroused the curiosity of researchers to investigate on the possibility achieve more efficient management throughout the whole life cycle of a construction project. In the Sri Lankan (SL) context, the construction industry places a vital role in economic and physical development. Furthermore, in the Sri Lankan economy, construction is the fourth highest sector after services, manufacturing, and agriculture. Therefore, it is vital to recognise the potential of IoT to be adopted in the industry, and associated barriers within such a process, which is the aim of this study. To attain the aim, an extensive literature synthesis was piloted to acknowledge the concepts and current practices of IoT applications in a global context. Literature synthesis revealed the global construction industry's faithfulness towards IoT applications, following a successful identification of potential barriers. Eventually, a conceptual model was developed to specify key variables that influence a phenomenon of interest while guiding SL construction professionals to recognize and adopt IoT applications in their respective fields.

Keywords: ***Internet of Things (IoT), Industry 4.0, construction informatics, Sri Lanka (SL)***

INTRODUCTION

Machines being able to do manual Work is a well-known concept, which led to the fourth industrial revolution (Husain, 2017). In such context, machines perform tasks without human influence, which will radically alter the way people live, operate, and communicate with each other. Accordingly, the Internet acts as a medium of communication (Madakam, 2015). The interconnection among people, is one of the core factors responsible for the level of economic development, that, in effect, drives more interconnections. (Farhadi et al., 2015). Identically, the interconnectivity among citizens outside geographical borders has increased by the emergence of the Internet, which enhanced economic activity level and increased volume of output, sales, profits, and wealth (Bianchi and Mathews, 2015).

70 percentage of the world's population is expected to live in cities by 2050 (Albino et al., 2015). Thereupon, to support such rapid growth, providing up-to-date information promptly through the adoption of new information and communication technologies to residents of cities is needed. Hence, the Internet of Things (IoT) is well known amongst the technologies as a promising solution for such need (Bi et al., 2014). However, Kodithuwaku (2019), emphasises that today, smart objects being invented within months, where time gaps between inventions are being shortened. In line with this development, the IoT is an area of innovation and growth (Vermesan and Friess, 2013).

The development of the IoT concept would change lifestyles and enhance the performance of the culture (Suriyarachchi et al., 2019). As a result, the construction industry will follow such rapid technological enhancements around the world. Accordingly, there are 367 IoT connected projects identified worldwide, whereas industrial-related are 265, and IoT connected building projects are 193 (Lueth, 2019). However, Jones (2017) insisted that carpenters, welders, and painters on the worksite might not discuss the IoT in casual conversation. Whereas, a growing number of industry-leading contractors and builders are using IoT devices to monitor equipment, machinery, and workers to make better decisions in real-time. Besides, IoT brings solutions for bottlenecks, which delaying Work down dramatically without supervisors knowing that is even happening in construction sites (Triax, 2018).

Therefore, the use of IoT applications should be acknowledged by the construction industry, as the industry will become ever more complicated in the future (Mahmud et al., 2018). In such a time, if there is no system for facilitation of the Work involved, the construction sector must take account of the expansion of the IoT network; otherwise, the construction sector will be left behind by other industries.

However, the Sri Lankan construction industry is lagging in the adoption of new technologies, concerning other countries (Suriyarachchi et al., 2019). Nevertheless, Sri Lanka, as a developing country, should also be ready to face the IoT system in the construction industry. There were several studies conducted in different contexts concerning the IoT in developed countries (Atayero et al, 2016; Mahmud et al., 2018). Despite those studies, there is a necessity to investigate the potential barriers faced by the global construction industry with the adoption of IoT, and the preparedness of Sri Lanka for a better adoption of IoT in construction industry.

Accordingly, this paper intends to bring in literal analysis to answer the question on “how far the Sri Lankan construction industry is ready to adopt IoT in assisting day to day on-site activities”. Accordingly, a conceptual model is presented at the end of this study to determine the outcomes of this paper. This paper is structured under five sections, initially the concepts, development, and the process of IoT was discussed and then, current practices of IoT in the construction industry were identified through a discussion of benefits of such applications in the global context. Next, an insight into the barriers faced by global construction industries was presented. Thereafter, attention is drawn to certain indices for the identification of IoT readiness of Sri Lanka. Finally, the conclusions have been drawn presenting the conceptual model for identification of barriers in SL construction industry.

INTERNET OF THINGS (IOT)

Censis (2019) expressed, the significant difference between the concept of Machine to Machine communication (M2M), and IoT, comes with the proliferation of connected devices, propelled by the advancement of technology. For instance, the data can be gathered and interpreted through the Internet, by installing low cost, a battery-operated sensor on objects. IoT was officially unveiled by the International Telecommunications Union (ITU) after Kevin Ashton coined the concept (ITU, 2015). The concept of IoT is identified as a system of Things using the Internet or a private network to connect and communicate with each other (Censis, 2019).

In particular, 'Things' are stipulated as 'smart devices' that are connected in to network and communicate among each other with minimum human engagement. Specifically, the International Telecommunication Union (2012) defined, IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) Things based on existing and evolving interoperable information and communication technologies". The basic idea is that objects of day-to-day life can be equipped with the detection, sensing, networking and processing capabilities that enable them to communicate over the Internet with each other and with other devices and services in order to achieve a common goal (Dooley et al., 2017). In such context, the IoT allows people and Things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service (Balte et al., 2015). Besides, the system enables to acquire, process, and react to real-world data in real-time.

Development of IoT

The Gartner Hype Cycle specifically focuses on the set of technologies that is showing promise in delivering a high degree of competitive advantage over the next 5 to 10 years, which is illustrated in Figure 1 (Gartner, 2017).

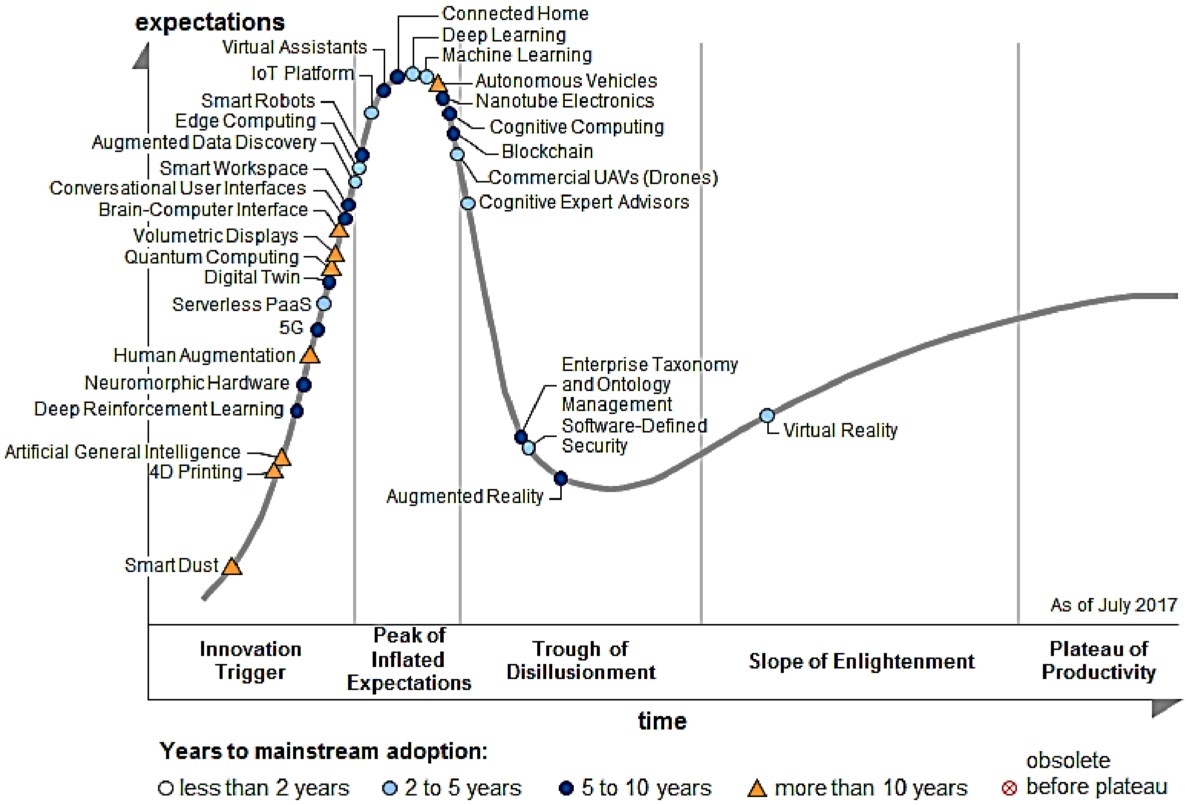

Figure 1: The Gartner Hype Cycle 2017
Source: (Gartner, 2017)

In such context, emerging technologies require revolutionizing the enabling foundations that provide the volume of data needed, advanced compute power, and ubiquity-enabling ecosystems (Lazari, 2020). Accordingly, implementation of IoT platforms will happen in 2-5 years, which will enable such needs. Besides, IoT is such promising technology which is pulling the other trends along the Hype Cycle.

Subsequently, rapid drops in the cost of microchips, sensors, and improvement of communications capability, increased the installation of these devices in objects all over the physical world (ITU, 2015). Therefore, technology firms and consulting firms predict billions of IoT devices to be installed in the next decade, with a total annual economic effect in trillions of US dollars (Manyika et al., 2013).

However, factors that are driving the growth of IoT is in the first and second stages of development path, where the attention of the real estate and construction industry remains, which is illustrated in Table 1.

Table 1: The development stages of IoT

Stage 1	Stage 2	Stage 3	Stage 4
Operational Efficiency	**New Products and Services**	**Outcome Economy**	**Autonomous, Pull Economy**
Asset utilization	Pay-per-use	Pay-per-outcome	Continuous demand-sensing
Operational cost reduction	Software-based services	New connected ecosystems	End-to-end automation
Worker productivity	Data monetisation	Platform-enabled market place	Resource optimisation and waste reduction

Source: (Dooley et al., 2017)

Moreover, Husain (2017) identified the development of IoT in three waves, which are:

Measuring and tracking: Husain (2017) recognized that people are currently in the midst of the first wave of IoT. For instance, there are wearables, and gadgets implemented to measure pulse rate and track day-to-day work activities, attempt to predict the circadian rhythm and triggering the alarm automatically if people fall asleep, and to alarm intruders in private places.

Modelling and predicting: There are circumstances identified, where data captured from first-a wave of devices were used by devices to model the environment, their behaviour, and the behaviour of other systems to predict the future. There are systems which include delivery drones, self-driving trucks and tractors, and increasingly sophisticated factory and warehouse bots that use vision to detect objects and sort products and packages.

Fully autonomous devices: In the third wave, the maximum potential of IoT will be recognized, where there will be federated network intelligence powering cognitive, fully autonomous devices. For instance, algorithms that empower fleets of hundreds of thousands of autonomous drones to carry out an ever-increasing range of functions for their human owners.

The process of typical IoT system

The revolution of IoT applications incorporates various types of technologies in a timely manner. Hence, the system process would be enhanced according to the situations. However, the step by step process of a typical IoT system is illustrated in Figure 2, in order to acknowledge the concept of IoT.

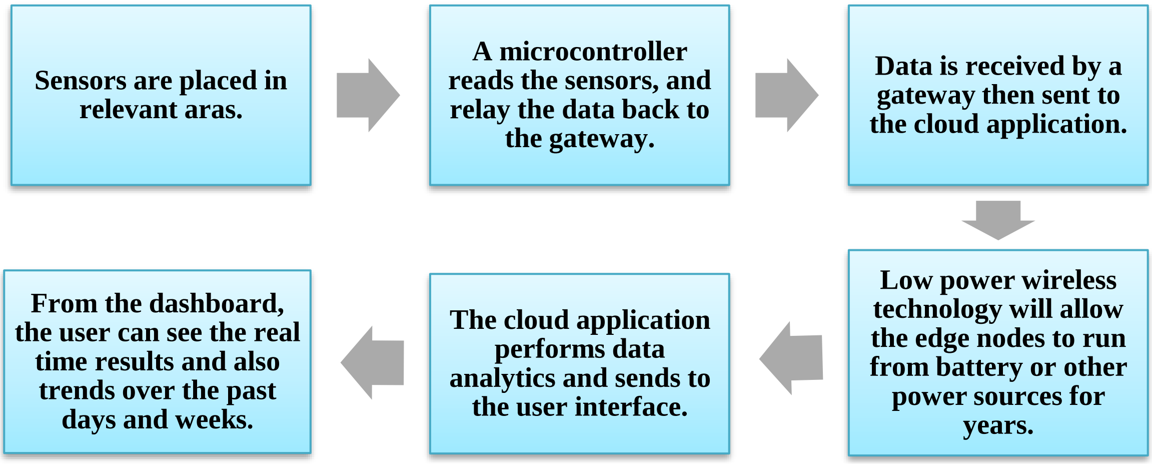

Figure 2: The Process of a Typical IoT System
Source: (Censis, 2019)

CURRENT PRACTICES OF IOT IN THE GLOBAL CONSTRUCTION INDUSTRY

There are significant number of IoT applications were implemented for both production and deployment of devices in the construction industry to maximise their opportunities (Atayero et al., 2016). Hence, such applications and relevant benefits are illustrated in Table 2.

Table 2: IoT applications

IoT Applications	Benefits	Authors identified
IoT- Designed smart wearable devices	Helps to track workers' health and safety by identifying pulse rate, temperature surrounding environment and other health measures and alert in real-time	(Mehata et al., 2019)
IoT Service mounted in Concrete batching plants	Improve the consistency of concrete quality, connected logistics, and predictive maintenance; Monitor the level of mixing of all aggregates and measure the weight of each aggregate; Calculates the rate of water in kg/sec to the batch to maintain the appropriate mix of gravel and cement in the receipt.	(Walther, 2018)
IoT sensors mounted in structures	Detect and analyse abnormal changes in relation to structures (changes in the underground water table, change in shape, load on external lateral support, and degree of slope, supporting) and issue appropriate warning signals to take remedial actions on time	(Lam et al, 2017)
IoT linked BIM model	Real-time data simulation for construction; facilitating dynamic interactions and real-time responses among designers, builders, transit providers, and maintainers.	(Ding et al., 2018)
Attached IoT labels on precast components	The fabrication method of such components, the comprehensive construction process, cost, and quality of the completed steel bridge can be identified; Steel-bridge performance can be monitored remotely; Big data analytics further evaluates sensor data into the decision-	(Ding et al., 2018)

	making model. Thereupon, the steel bridge can be predictively and proactively maintained.	
IoT System in Building	Represents the energy usage of the buildings accounted for in real-time. Therefore, Energy consumption monitoring helps in improve energy efficiency, decrease waste, and be favourable to sustainable development	(Bottaccioli, et al., 2017)
IoT in Green building	The Green building concept achieves its goals through the use of (IoT) technology and cloud computing with the green building energy efficiency standards; environmental monitoring, provides supervision.	(Wang et al., 2017)
IoT in a utility tunnel with BIM model	Surrounding dust monitoring systems, automatic sprinkler dust falling control systems, and site temperature monitoring systems based on real-time metrological data; better space, gate management of tunnel	(Wu et al., 2018)
Usage of drones	Conduct surveys high precisely, and real-time observation of changing topography of worksites.	(Sategna et al., 2019)
IoT system used for asphalt laying process	Better asphalt temperature, delivery management throughout the process	(Kuenze et al., 2016)
Intelligent building	Sensors collect property and user data to increase user friendly.	(Nair, 2020)
IoT sensors attached in internal transport platforms	The supervisors on their smartphones were able to figure out where the lifts were and whether one was available instantly.	(Triax, 2018)
IoT sensors used in hazardous areas	The regional workers were able to leave the hazardous field on time.	(Zhou and Ding, 2017)
Smart contract management	Payment, contractual terms, conditions management	(AIQS, 2019)

BARRIERS FOR THE ADOPTION OF IOT IN GLOBAL CONTEXT

Since IoT creates more opportunities and customised services, industrial parties are making significant investments in IoT solutions. However, despite the opportunities, industries are facing potential barriers in IoT adoption, holding them back from adopting the technology. Hence, such common barriers are recognised below.

Barriers Related to Individual Parties

Unwillingness to lose current job opportunities: A significant group of respondents says that the progressive disappearance of highly skilled jobs is the consequence of such new technologies (Smith, 2014). For instance, heavy machinery operators face the possibility of being phased out of their position before the emergence of automated navigation. Such jobs are taken over by software developers. Additionally, current competitive areas of professionals needed to be extended to machine learning and IT development. Therefore, people tend to be comfortable enough in conventional methods rather than adopting new contexts.

Operating methods are inadequately acknowledged: Employees decide to follow their way of operation without acknowledging systems' instructions (Sategna et al., 2019). Therefore, there will be unfavourable impacts on the performance of machines and construction. In addition, the employees and contractors subsequently intend to take charge of the process manually, if they consider that the devices do not correspond to their preferences. Hence, such context leads to significant delays and failure of the project.

Hesitation to try new technologies, with theoretical knowledge: In consideration of workers' training experience, they had to have only the theoretical knowledge of the operation of new technologies (Goos, 2018). Conversely, they need to experience such technologies at the site physically. A considerable amount of time needs to be spent on adopting new technologies in-work cycle in order to prevent mistakes (Sategna et al., 2019). However, People remain unconvinced about the way that collection and optimisation of data from IoT (Dooley et al., 2017)

Barriers Related to Organisations

Complexity: Due to the scale and complexity of large companies, the digital transformation might take a considerable time (Miorandi et al, 2012). However, in the future digital scenario, larger companies can become trend-setters for such technologies.

Digital transformation is particularly burdensome for construction SMEs: The high cost of capital funding for new digital tools and technology is burdensome for small and medium contractors (Cassetta et al., 2019). Further clarified that SMEs are afraid of negative impacts following the adoption of digital technologies and inadequacy of the right skills and abilities to supervise the maintenance of fully digital equipment. Therefore, they choose to follow the old practices, instead of losing their freedom to a third party.

Fear of Return on Investment: Most organisations would like to have a significant return on investment before they deal with the challenges of digital transformation (Wu et al, 2006). In such a context, SMEs are unwilling to adopt IoT technology to their businesses, without knowing the real benefits of IoT.

Fear of privacy issues: The contractors and Original equipment manufacturers are highly invested organisations. Therefore, organisations are not willing to share information for risk of losing their confidential information, and experience to the benefit of third parties (Neshenko et al., 2019). Besides, Since the data transmission happening on a wireless network, situations of cybercrime are demotivating the stakeholders on adopting IoT technology for procurement.

Resource Related Barriers

Accuracy: For instance, Chaves and Decker (2010) identified that the temperature of things, inside the container, could not be detected uniformly by the sensor, and things might show different characteristics in various points. Therefore, A single IoT sensor will detect an inaccurate condition of such materials.

Cost: RFID tags will produce high magnitudes of information. Furthermore, the cost of an RFID sensor is high in a retailer's cost-sensitive supply chain (Chaves and Decker, 2010). Similarly, devices, which can enhance the gateway compatibility, are identified as costly devices universally. Accordingly, organisations needed to be financially stable on the initial investment (Chen et al., 2014)

Production: Sategna et al. (2019) expressed that solutions that might perform better in one market cannot be replicated easily in other countries since the environment might be more fragmented in other places. Besides, the need to meet different market conditions can reduce commercial activity.

Network connectivity: Qing (2019) emphasis network coverage provided by network providers was not enough for the better transmission of data in real-time in rural areas. Besides fluctuating signals would interrupt the performance of devices (Gan et., 2011).

Potential databases: Unavailability of potential databases to process, and store the data will be identified as a barrier. Besides, such platforms needed to be accessed by various places and hold the working load of the connected devices (Diedrichs, et al., 2014).

Security-Related Barriers

Untrustworthy of wireless transmission: Yuqiang et al. (2010) expressed that transmission data tend to be related to labels information of items in the IoT network. Among these items, information is likely to involve some confidential nature information, especially in each IoT' system in the process of interaction. Once the information is leaked or defaced, the loss is immeasurable.

Eavesdrop privacy and replay attack: An eavesdropper could easily steal transmission information from the wireless devices due to the wireless data transmission, thus acquiring important business information (Geneiatakis et al., 2017). Besides, according to the reader and label data communication of eavesdropping, obtain data information from repeating front communication behaviour.

Forward security and synchronicity damage: A hacker could try to use current leaked keys to deduce previous old keys, thus, to make unfavourable actions (Medwed, 2016). Besides, the hacker could try to produce different keys among database and IoT tag, thus making the reader unable to access keys produced by IoT tags from the database, which leads to failure of communication.

Position tracking: Hacker could intrude through position tracking sensors to acquire product details, and change the destination of products (Neshenko et al., 2019).

Regulatory Implications

The deployment of IoT systems, and their potential impact on individuals and businesses, are encountered regulatory issues which are illustrated in Table 3.

Table 3: Regulatory Implications

Implication	Description
Licensing and spectrum management	Licensing and spectrum management is an essential issue for ensuring availability and capacity for IoT communications. IoT devices communicate using a range of different protocols based on their connectivity requirements and resource constraints. These include short-range radio protocols such as ZigBee, Bluetooth, and Wi-Fi, mobile phone data networks.
Switching and roaming	Standard mobile telephony network SIMs and accounts unsuitable for large M2M users, mobile devices, and fixed devices in areas of poor reception.
Addressing and numbering	Enabling peer-to-peer connections between devices can increase to interact with nearby devices. However, where devices must be globally reachable – most likely, via the Internet – a large address space is required to identify each one individually.

Source: (Bandyopadhyay and Sen, 2011**;** Bucchiarone et al., 2019; ITU, 2015; Mehata et al., 2019)

Other Barriers

Lack of commonly agreed standards and low interoperability: The absence of universally agreed standards and less interoperability represents a barrier to digital transformation for most organisations in the construction industry. In specific, clients with mixed fleets are cautious about adopting digital technologies, since they could not precisely analyse, and compare the results, due to the absence of commonly accepted communication standards for data sharing (Gomez and Bajaj, 2019).

THE READINESS OF SRI LANKA FOR IOT ADOPTION

The developing economies of Sri Lanka is having an opportunity to engage in adopting the IoT evolution at the developmental stage (Athukorala et al., 2017). In such a case, maximising the opportunities and benefits of IoT depends on the level of preparedness in technology as a country (Cisco, 2015). Therefore, several technical organisations formulated indices by analysing critical elements associated with IT infrastructure and IoT to acknowledge the level of readiness of countries (Atayero et al., 2016).

Network Readiness Index (NRI)

The NRI evaluates how conducive a country is to the development of a network of information and communication technologies (Baller et al, 2016). Besides, Since the IoT depends on the interconnectedness of things, NRI index is a better tool to measure the medium of interconnectivity. The Sri Lankan economy is scored 42.42 out of 100 as per the 2019 network readiness index (Dutta and Lanvin, 2019). In such context, Sri Lanka is scored 40.46, 28.36, 54.66, and 46.19 in respect to the level of technology, application of ICT by people, conduciveness of the national environment and impact of participation in economy wise. This shows that Sri Lanka is having less network affordability and lagging as less network-ready region, to facilitate IoT.

ICT Development Index (IDI)

The index emphasis the readiness of economies to be ICT-driven and the intensity, accessibility of ICT usage in the infrastructure of the country (Atayero et al., 2016). Besides, adequacy and utilisation of skills needed for such ICT infrastructure were taken into account to formulate the index (International Telecommunication Union, 2017). Accordingly, Sri Lanka had a global rank of 117 out of 166 countries in the IDI, in 2017 (Digital Infrastructure and Information Technology Division, 2017). Therefore, such results reveal that the ICT infrastructure of Sri Lanka is not in a favourable position to facilitate the IoT, comparing to other developed countries. However, Sri Lanka is one of the countries, which having the lowest mobile-broadband prices to access the internet. This would be an advantage for the adoption of IoT.

Global Innovation Index (GII)

The innovative solutions for the development of network and ICT infrastructure depend on the innovating capabilities of the country. Hence examining such capabilities would help to facilitate IoT in the country. In such a context, GII emphasis the innovative solutions implemented and factors incorporated for such implementation. In addition, governance facilitation, level of investment, freedom for creativity, availability of resources, knowledge sharing, competitive working are the factors examined for implementing innovations. Accordingly, SL ranked in 101st Position out of 129 economies in the Global Innovation Index 2020 (Dutta et al., 2020). Besides, SL categorised under the lower-middle-income group holding 12,132.7$ GDP per capita in purchasing power parity. The slow progress in the index rankings reflects Sri Lanka’s weak political and regulatory environment, poor spend and performance in human capital and research and difficultly in accessing the credit in funding innovations.

The Global Competitiveness Index (GCI)

The Index emphasis the essential factors needed to facilitate competitiveness such as strong institutions that enable freedom enterprise, competitiveness and protection of intellectual property rights (Atayero et al., 2016). In addition, the index considers both social and physical infrastructure, sound macroeconomic environment in the country. Factors that facilitate efficiency in competitiveness encapsulate higher level of education coupled with market opportunities as well as technological readiness. In case, SL scored 57.11 points out of 100 on the 2018 Global Competitiveness Report (Schwab, 2019). This indicates that SL needs to consider investment activities for innovation, creativity and development.

As a result of the above rankings, SL seems to be lagging in all the indices used to examine the readiness of SL in adopting IoT. This indicates that the region demands strong institutions that can make huge investments, adequate ICT infrastructure, innovations that facilitate the delivery of affordable services and a market that promotes competitiveness.

CONCEPTUAL MODEL FOR PHENOMENON OF INTERESTS IN IOT ADOPTION

The conceptual model, which is illustrated in Figure 3, was developed in order to guide the reader to the ultimate concept of the study.

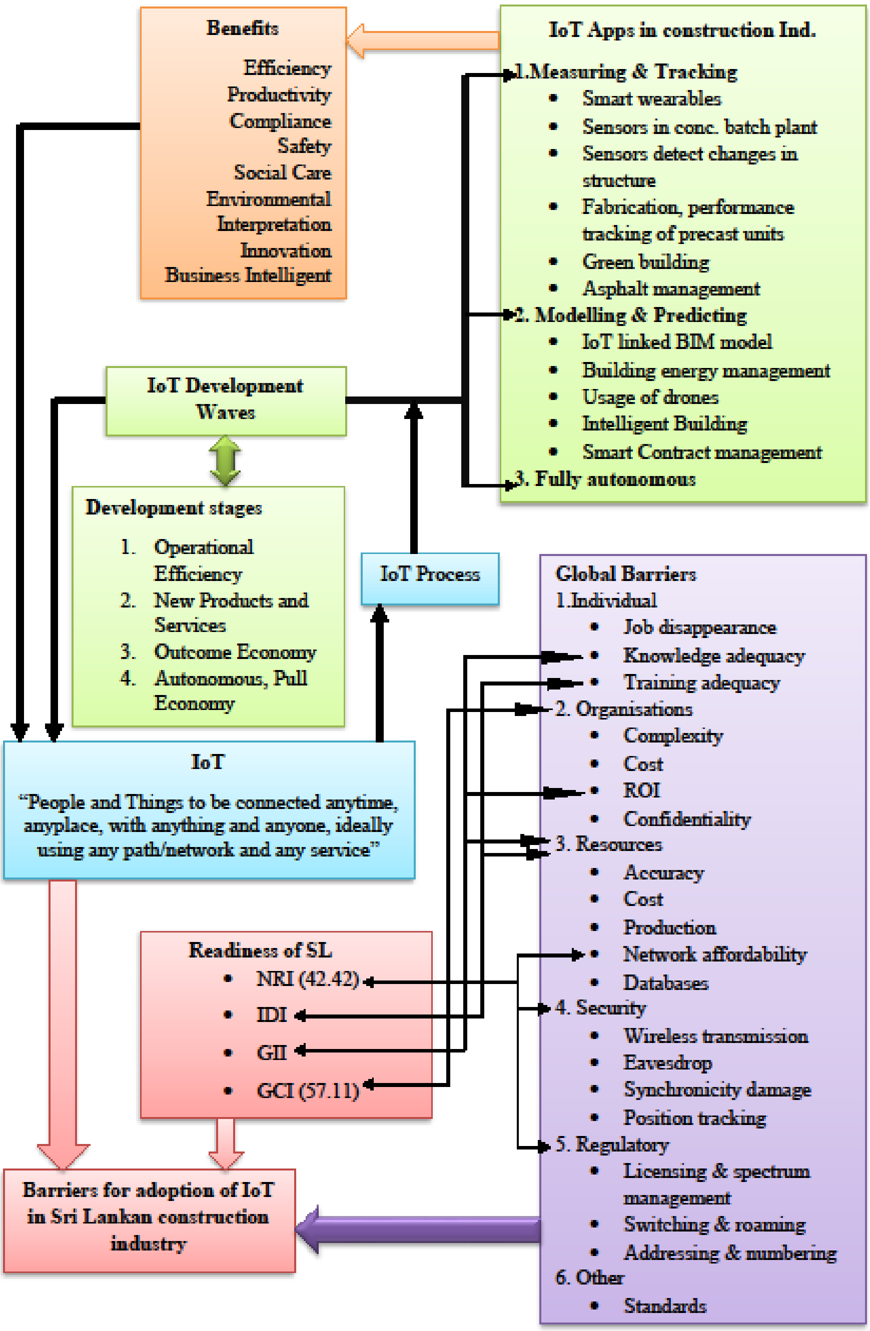

Figure 3: The Conceptual Model

Initially, concepts, process and development of IoT are presented, in order to identify the capabilities of IoT. Accordingly, applications practised in construction industry were established. Subsequently, significant types of barriers would be interpreted with IoT concepts and applications identified. Besides, the level of preparedness of SL in adopting IoT is established in the expectation of investing the global barriers in the SL context. Eventually, the detailed concepts and benefits identified from the various applications, will fuel the adoption of IoT applications.

CONCLUSIONS

The literature review aimed at identifying the background of IoT concepts by bringing literal ideas from significant authors. Accordingly, the IoT allows people and Things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service. However, the development of IoT applications is still in measuring, tracking and modelling stage out of its maximum potential of autonomous applications. It is ensured by the identification of several current applications of IoT. Besides, the typical IoT application process corporate with mechanisms of such IoT applications. Moreover, significant benefits identified from such applications emphasis the potential impact of IoT in the construction industry.

Thereafter, critical barriers faced by the individual parties and organisations are presented, which showcase that technology needs to be properly acknowledged and necessary actions needs to be taken to facilitate the IoT applications in the construction industry. Besides several indices identified by the organisations were discussed, which indicate Sri Lanka is less prepared for the adoption of IoT, comparing to other countries. Eventually, Theoretical framework explains the path for the investigation of identified barriers in SL context; thus, better IoT adoption can be done in SL by overcoming such barriers by formulating suitable solutions.

REFERENCES

AIQS. (2019, December). *Build Environement Economist*, 1-60.

Albino, V., Berardi, U., and Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Urban Technology, 22*(1), pp.3-21.

Atayero, A. A., Oluwatobi, S. O., and Alege, P. O. (2016). An assessment of the Internet of Things (IoT) adoption readiness of Sub-Saharan Africa. *Journal of South African Business Research*, pp.1-13.

Athukorala, P. C., Ginting, E., Hill, H., and Kumar, U. (Eds.). (2017). *The Sri Lankan economy: Charting a new course.* Metro Manila: Asian Development Bank.

Baller, S., Dutta, S., and Lanvin, B. (2016). *The global information technology report 2016: Innovating in the digital economy.* Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/GITR2016/GITR_2016_full%20report_final.pdf

Balte, A., Kashid, A., and Patil, B. (2015). Security issues in Internet of Things (IoT): A survey. *International Journal of Advanced Research in Computer Science and Software Engineering, 5*(4), pp.450-455.

Bandyopadhyay, D., and Sen, J. (2011). Internet of Things: Applications and challenges in technology and standardization. *Wireless Personal Communications, 58*(1), pp.49-69.

Bi, Z., Xu, L. D., and Wang, C. (2014). Internet of Things for enterprise systems of modern manufacturing. *IEEE Transactions on Industrial Informatics, 10*(2), pp.1537-1546.

Bianchi, C., and Mathews, S. (2015). Internet marketing and export market growth in Chile. *Journal of Business Research*, pp.1-9.

Bottaccioli, L., Aliberti, A., Ugliotti, F. M., Osello, A., Macii, E., Patti, E., and Acquaviva, A. (2017). Building energy modelling and monitoring by integration of IoT devices and Building Information Models. *IEEE 41st Annual Computer Software and Applications Conference* (pp. 914-922). Italy: IEEE.

Bucchiarone, A., Sanctis, M. D., Hevesi, P., Hirsch, M., Abancéns, F. J., Vivanco, P. F., . . . Lukowicz, P. (2019). Smart construction: Remote and adaptable management of construction sites through IoT. *IEEE Internet of Things Magazine,* pp.38-45.

Cassetta, E., Monarca, U., Dileo, I., Berardino, C. D., and Pini, M. (2019). The relationship between digital technologies and internationalisation: Evidence from Italian SMEs. *Industry and Innovation, 27*(4), pp.311-339.

Censis. (2019). *Getting started with IoT: Exploring IoT (Internet of Things) for business growth [Brochure].* Glasgow: Censis.

Chaves, L. W., and Decker, C. (2010). A Survey on organic smart labels for the Internet-of-Things. *Seventh International Conference on Networked Sensing Systems (INSS).* Kassel: IEEE.

Chen, S.-L., Chen, Y.-Y., and Hsu, C. (2014). A new approach to integrate Internet-of-Things and software-as-a-service model for logistic systems: A case study . *Sensors,* pp.6144-6164.

Cisco. (2015). *Harnessing the Internet of Things for global development.* Geneva: Author. Retrieved from http://ssrn.com/abstract=2588129

Cisco. (2016). *Cisco visual networking index: Global mobile data traffic forecast update, 2015–2020.* USA: Author. Retrieved from https://www.cisco.com/c/dam/m/en_in/innovation/enterprise/assets/mobile-white-paper-c11-520862.pdf

Diedrichs, A. L., Tabacchi, G., Grünwaldt, G., Pecchia, M., Mercado, G., and Antivilo, F. G. (2014). Low-power wireless sensor network for frost monitoring in agriculture research. *IEEE Biennial Congress of Argentina (ARGENCON).* Bariloche, Argentina: IEEE.

Digital Infrastructure and Information Technology Division. (2017). *ICT Indexes.* Colombo: Author. Retrieved from http://www.mdiit.gov.lk/index.php/en/ict-indexes#:~:text=Sri%20Lanka%20had%20a%20global,Networked%20Readiness%20Index%20(NRI).

Ding, K., Shi, H., Hui, J., Liu, Y., Zhu, B., Zhang, F., and Cao, W. (2018). Smart steel bridge construction enabled by BIM and Internet of Things in industry 4.0: A framework. *IEEE 15th International Conference on Networking, Sensing and Control (ICNSC).* Zhuhai: IEEE.

Dooley, K., Ihasalo, H., Jylhä, T., and Sairanen, S. (2017). *IoT market analysis in the Finnish estate and construction sector: Market analysis.* Finland: Granlund.

Dutta, S., Lanvin, B., and Vincent, S. W. (2020). *Global innovation index.* Geneva: The Confederation of Indian Industry. Retrieved from https://www.globalinnovationindex.org/gii-2020-report#

Farhadi, M., Islam, M. R., and Moslehi, S. (2015). Economic freedom and productivity growth in resource-rich economies. *World Development, 72*, pp.109-126.

Gan, G., Lu, Z., and Jiang, J. (2011). Internet of Things security analysis. *International Conference on Internet Technology and Applications.* Wuhan: IEEE.

Gartner. (2017). *Gartner says 8.4 billion connected "Things" will be in use in 2017, up 31 percent from 2016.* Egham, U.K.: Author. Retrieved from https://www.gartner.com/en/newsroom/press-releases/2017-02-07-gartner-says-8-billion-connected-things-will-be-in-use-in-2017-up-31-percent-from-2016

Gartner. (2017). *Top trends in the Gartner Hype Cycle for emerging technologies.* Stamford: Author. Retrieved from https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

Geneiatakis, D., Kounelis, I., Neisse, R., I, N. F., Steri, G., and Baldini, G. (2017). Security and privacy issues for an IoT based smart home. *40th International Convention on Information and Communication Technology* (pp. 1292-1297). Opatija: IEEE.

Gomez, A. K., and Bajaj, S. (2019). Challenges of testing complex Internet of Things (IoT) devices and systems. *11th International Conference on Knowledge and Systems Engineering (KSE).* Da Nang: IEEE.

Goos, M. (2018). The impact of technological progress on labour markets: Policy challenges. *Oxford Review of Economic Policy, 34*(3), pp.362-375.

Husain, A. (2017). *The sentient machine: The coming age of artificial intelligence.* New York: Scribner. Retrieved from https://www.amazon.com/Sentient-Machine-Coming-Artificial-Intelligence/dp/1501144677

International Telecommunication Union. (2017). *Measuring the information society report 2017.* Geneva: Author. Retrieved from https://www.itu.int/net4/ITU-D/idi/2017/index.html#idi2017rank-tab

ITU. (2015). *GSR discussion paper: Regulation and the Internet of Things.* Geneva: Author.

ITU. (2015). *Regulation and the internet of things.* Geneva: Author. Retrieved from https://www.itu.int/en/ITU-

D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf

Jedermann, R., Garcia, L. R., and Lang, W. (2009). Spatial temperature profiling by semi-passive RFID loggers for perishable food transportation. *Computers and Electronics in Agriculture, 65*(2), pp.145-154.

Knoema. (2012). *Knowledge economy index.* Author. Retrieved from https://knoema.com/aomssce/knowledge-economy-index

Kodithuwaku, M. (2019). Industry 4.0 and construction 4.0. *Quantity Surveyor's Adaptability to a Challenging Economy* (pp. 21- 31). Colombo: Institute of Quantity Surveying Sri Lanka.

Kortuem, G., Kawsar, F., Sundramoorthy, V., and Fitton, D. (2009). Smart objects as building blocks for the Internet of things. *IEEE Internet Computing, 14*(1), pp.44-51.

Kuenze, R., Teizer, J., Mueller, M., and Blickle, A. (2016). SmartSite: Intelligent and autonomous environments, machinery, and processes to realize smart road construction projects. *Automation in Construction*.

Lam, R. C., Junus, A., Cheng, W. M., Li, X., and Lam, L. C. (2017). IoT application in construction and civil engineering works. *International Conference on Computational Science and Computational Intelligence (CSCI)* (pp. 1320-1325). Las Vegas: IEEE.

Lazari, J. (2020). *Meet the five emerging technology trends that will blur the lines between human and machine.* Lewisville: Sumig. Retrieved from https://robotics.sumigusa.com/blogs/news

Lueth, K. L. (2019). *IoT platform companies landscape 2019/2020: 620 IoT platforms globally.* Hamburg, Germany: Iot-analytics. Retrieved from https://iot-analytics.com/iot-platform-companies-landscape-2020/

Madakam, S. (2015). Internet of Things: Smart things. *International Journal of Future Computer and Communication, 4*(4), pp.250-253.

Mahmud, S. H., Assan, L., and Islam, R. (2018). Potentials of Internet of Things (IoT) in Malaysian construction industry. *Annals of Emerging Technologies in Computing (AETiC), 2*(4), pp.44-52.

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., and Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy.* McKinsey Global Institute. Retrieved from https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/disruptive-technologies#

Matthews, K. I. (2019). *Digital transformation and the Internet of Things.* Atlanta, Georgia, USA: Georgia Institute of Technology (Georgia Tech).

Medwed, M. (2016). IoT security challenges and ways forward. *Proceedings of the 6th International Workshop on Trustworthy Embedded Devices.* TrustED '16.

Mehata, K. M., Shankar, S. K., Karthikeyan, N., Nandhinee, K., and Hedwig, P. R. (2019). IoT based safety and health monitoring for construction workers. *1st International Conference on Innovations in Information and Communication Technology (ICIICT). 5.* Chennai: IEEE.

Miorandi, D., Sicari, S., Pellegrini, F. D., and Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Networks, 10*(7), pp.1497-1516.

Nair, R. (2020). *Build smarter spaces! Know 2019's top intelligent building trends.* Dubai. Retrieved from https://gbmme.com/newsroom/build-smarter-spaces-know-2019s-top-intelligent-building-trends/

Neshenko, N., Harb, E. B., Crichigno, J., Kaddoum, G., and Ghani, N. (2019). Demystifying IoT security: An exhaustive survey on IoT vulnerabilities and a first empirical Look on Internet-scale IoT exploitations. *Communications Surveys and Tutorials , 21*(3), pp.2702-2733.

Oesterreich, T. D., and Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry, 83*, pp.121-139.

Qing, A. T. (2019). *Exploring the adoption of Internet of Things in Malaysian construction industry.* Universiti Tunku Abdul Rahman.

Sategna, L. G., Meinero, D., and Volontà, M. (2019). *Digitalising the Construction Sector*, pp.1-100.

Schwab, K. (2019). *The global competitiveness report.* Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

Smith, P. (2014). BIM and the 5D project cost manager. *Procedia - Social and Behavioral Sciences, 119*, pp.475-484.

Stergiou, C., Psannis, K. E., Kim, B. G., and Gupta, B. (2016). Secure integration of IoT and cloud computing. *Future Generation Computer Systems*.

Suriyarachchi, C., Waidyasekara, K., and Madhusanka, N. (2019). Integrating Internet of Things (IoT) and facilities manager in smart buildings: A conceptual framework. *The 7th World Construction Symposium 2018 : Built Asset Sustainability : Rethinking Design Construction and Operation* (pp. 325-334). Colombo , Sri Lanka:

Triax. (2018). *Demystifying the Internet of Things for construction.* Norwalk: Author.

Vermesan, O., and Friess, P. (2013). *Internet of Things: Converging Technologies for Smart Environments and Integrated Ecosystems.* Aalborg: River Publishers.

Walther, T. (2018). Digital transformation of the global cement industry. *IEEE-IAS/PCA Cement Industry Conference (IAS/PCA).* Nashville: IEEE.

Wang, M., Qiu, S., Dong, H., and Wang, Y. (2017). Design an IoT-based building management cloud platform for green buildings. *Chinese Automation Congress (CAC)* (pp. 5663-5667). Jinan: IEEE.

Wu, C. M., Liu, H. L., Huang, L. M., Lin, J. F., and Hsu, M. W. (2018). Integrating BIM and IoT technology in environmental planning and protection of urban utility tunnel construction. *IEEE International Conference on Advanced Manufacturing (ICAM)* (pp. 198-201). Yunlin: IEEE.

Wu, N. .., Nystrom, M. A., Lin, T. R., and Yu, H. C. (2006). Challenges to global RFID adoption. *Technovation*, *26*(12), pp.1317-1323.

Xu, X., Chen, T., and Minami, M. (2012). Intelligent fault prediction system based on Internet of Things. *Computers and Mathematics with Applications*, *64*(5), pp.833-839.

Yuqiang, C., Jianlan, G., and Xuanzi, H. (2010). The research of Internet of things' supporting technologies which face the logistics industry. *International Conference on Computational Intelligence and Security.* Nanning: IEEE Computer Society.

Zhou, C., and Ding, L. Y. (2017). Safety barrier warning system for underground construction sites using Internet-of-Things technologies. *Automation in Construction*, pp.1-18.