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Omar Sedeeq Yousif
Universiti Teknologi Malaysia

Rozana Zakaria
Universiti Teknologi Malaysia

Eeydzah Aminudin
Universiti Teknologi Malaysia

Nur Izyan Liyana Umran
Universiti Teknologi Malaysia

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Monitoring the Construction Industry Towards a Construction Revolution 4.0

Omar Sedeeq Yousif[1*], Rozana Zakaria[1], Noraziah Wahi[2], Eeydzah Aminudin[1], Asniza Hamimi Abdul Tharim[3], Jawa Anak Gara[1], Nur Izyan Liyana Umran[1], Ruzaini Khalid[1], Noraliza Ismail[1]

[1] School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[2] Faculty of Architecture Planning and Surveying, Universiti Teknologi MARA, Sarawak 94300, Malaysia
[3] Department of Built Environment Studies and Technology, Faculty of Architecture, Planning and Surveying, Universiti Teknologi MARA, Perak 32610, Malaysia

Corresponding Author Email: syomar2@graduate.utm.my

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ABSTRACT

The key concept of the Industrial Revolution IR 4.0 has been conceptualized as the new wave of digitalization, robotization, and broader usage of information and communication technology. However, the construction industry is complicated, which has led to its slow industrial evolution. The construction industry still follows traditional labor-intensive industry practices, with high energy consumption, environmental pollution, and low productivity in project delivery. Moreover, the recent cataclysmic COVID 19 pandemic has opened the vision of the construction industry towards IR 4.0 due to the human movement restriction. This paper aims to investigate the adoption of indispensable monitoring technology in the construction industry as effective visual communication of data towards the IR 4.0. This research closes the gap and gives an intensive literature investigation to acquire insights into Construction 4.0 and a case study to showcase the developed monitoring dashboard. Adoption of IR 4.0 technologies will achieve sustainable construction development, lower costs and fast construction with the highest quality. The critical literature review of previous studies with content analysis to demonstrate the recent research in this area. The monitoring dashboard brings the construction performance assessment data to real life and provides key performance indicators required for construction management and support decisions.

1. INTRODUCTION

The Industrial Revolution has recently become the foundation and pillar of industries, the most important of which is the construction industry. The Industrial Revolution is the development of the processes from traditional to intelligent by adopting advanced and intelligent technologies that will undoubtedly raise the production, construction, and performance levels to the optimum [1]. The previous three industrial revolutions were the basis and essence of the development of this fourth revolution, which depends mainly on digitization, robotics, and smart technologies [2]. However, the IR 4.0 focuses on the transformation of industries to digital intelligence, as this revolution is based on essential foundations consisting of big data analytics and cybersecurity, Internet control of things and services, augmented and virtual reality simulation, performing actions with the help of programmed and intelligent robots, additive manufacturing, integration systems, and cloud computing. These foundations are essential and have an impact on all industries, especially the construction industry, to increase efficiency, quality, and productivity [3].

With the introduction of IR 4.0, the construction sector undergoes a substantial transformation that will lead to the development of a more digitally integrated industry. In terms of embracing the foundations of the fourth revolution with process automation and digitization, the adoption is yet in its infancy and the construction industry falls behind in comparison to other industries [4]. There must be an inevitable impact when adopting any new revolution, whether positive or negative, on all economic, social, and cultural levels. The implications of smart and digital technologies on the construction industry show that they assist the sector to improve projects performance, management, and productivity by saving construction time, lowering costs, reducing construction faults or clashes, and improving work quality [5]. The term "Construction 4.0" was introduced to define and improve the construction industry by utilizing intelligent and latest digital technologies, and modern construction methods among construction stakeholders to raise the level of productivity to compete with the global construction industry and the ability to compete with other industries to contribute to the economic, social and cultural development of the country [6]. For instance, according to El Jazzar et al. [7], fourth industrial revolution can be defined as “a new technological age for manufacturing that uses cyber-physical systems and internet of things, data and services to connect production technologies with smart production processes”. In the construction research field of the twenty-first century, the term "Construction 4.0" has recently evolved. The growth of numerous technologies, the substantial change in investor needs, the shift toward mass customization, and the necessity for green building and sustainability are all driving interest in Construction 4.0 [8].

Currently, the construction data generated around the world is enormous and overwhelming. We use a variety of techniques and methods to analyze and manage these enormous data sources across a multitude of activities. In the coming decades, one of the most important skills will be the ability to extract, process, and understand this data to visualize it and get important information from that big and scattered data. As a result, the complementary scare element is the capability to recognize that data and elicitation value from it [9]. One of the IR 4.0 technologies is the dashboards, it provides a flexible entrepreneur portfolio that encompasses vendor profiles, performance forecasting and information management, and simultaneous monitoring. The dashboards provide information in an integrated manner, which will facilitate the exchange and sharing of information between construction parties, including contractors, authorities, and consultants. This dashboard will provide a sharing platform for the construction industry to move away from its individuality towards engaging and sharing information between construction concessionaires networks [10].

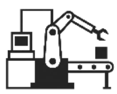
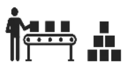
Wherefore, extensive research is required in this field. Thus, this research aims to investigate the adoption of indispensable monitoring technology in the construction industry as effective visual communication of data towards the IR 4.0. A comprehensive and in-depth critical literature review to get a whole picture and vision about Construction 4.0 and a case study to showcase the developed monitoring dashboard. Analyzing the technologies of IR 4.0 and their synchronization with the construction industry to fulfill the interest, avoid risks and achieve sustainable construction development. These were accomplished by analyzing researches in the construction sector from 2015 to the present based on the context and the series of keywords utilized for this analysis. Based on content analysis, the main keywords on which the research was built were construction revolution 4.0, construction life cycle, and dashboard. The profound critical literature review of scientific journals, books, thesis's, reports published, and conference papers all in the English language that could be retrieved from several databases such as Web of Science, ScienceDirect, Scopus, IEEE Xplore, and Google Scholar.

Construction monitoring can be facilitated by the use of IR 4.0 technologies such as dashboards, which are becoming more and more popular, having various benefits such as efficiency, low cost of development and operation, and exposure to construction performance. The study dug deep into the literature to identify a variety of aspects, beginning with IR 4.0 to the synchronization between the construction sector and IR 4.0. This is followed by an overview of the studies concerning in visual communication of data in the construction industry. From the content analysis of the critical literature review, did not find any study combining the green highway rating index with a carbon footprint calculator to improve the green highway performance and transform this integration into a web-based visualization monitoring dashboard. This paper presents a developed web-based monitoring dashboard for the green highway performance monitoring to enhance the decision support system to provide a better way of decision making in predictive green initiatives. The web-based monitoring dashboard is developed based on real-time data acquisition.

2. INDUSTRIAL REVOLUTION IR 4.0

The industry has developed from the end of the eighteenth century to the present day through four revolutions, each of which had an impact on the economy and the development of societies. It started with steam power, mechanization, and manufacturing industries at the end of the eighteenth century. Until the discovery of electrical power and assembly lines to increase productivity and production in the twentieth century, then the advanced radical factor entered, which is computerization that changed the industry in all its sectors. The industry began its fourth era in this current century, which relies mainly on the intellect and artificial intelligence to lead the revolution. The recent revolution is based on the principle of integrating skills and technology to eliminate the divides and merge the physical and digital domains [11]. To take a look into the four revolutions of industry, Table 1 shows this in brief.

Table 1. The four stages of the industrial revolution

Industrial Revolution	Period	Technologies
 IR 4.0	2011 – Present	Big Data, Cyber Physical System, Additive Manufacture, Cloud Computing, Virtual and Augmented Reality, RFID, Drones, etc.
 IR 3.0	Start of the 1950s	Automation, Computers, and electronics
 IR 2.0	Start of 20th Century 1870 – 1914	Mass production, Assembly line, Electrical energy
 IR 1.0	End of 18th Century 1760 ~ 1830	Mechanization, Steam power, Weaving loom

The fourth revolution will radically and inevitably change the shape of the industry and quickly to keep pace with the need for progress and development and it will be faster than its predecessors as there is a keen interest in the new future technology globally, but there is no single definition that can describe this giant revolution that will undoubtedly affect all aspects of life. Nevertheless, it could be described as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes", or "a new level of value chain organization and management across the lifecycle of products and services" [11]. These technologies have slowly made their way into many areas of the construction industry in recent years to help with efficient design optimization, emissions reduction, performance evaluation, resource management, energy savings, risk monitoring, and project delivery. Despite these advancements, intelligent processes in construction are still in their infancy, lagging behind other industries [12]. When the fourth revolution is adopted and the use of its modern technologies will increase productivity, which will create a great demand for new jobs that depend on these technologies, and will lead to the dispensation of some of the current jobs. This will open the doors to countless revenues and benefits. When adopting any new technology, there must be fear of its effects on the industry, such as the loss of traditional job opportunities [13].

3. CONSTRUCTION INDUSTRY AND IR 4.0

The construction industry has a significant impact on the natural environment, the country's economy, and the community as a whole. Since residences, offices, and transportation are all divisions of the construction sector, it will keep defining humans' lives in many ways. Construction is being highly complicated, with financial and time pressures increasing and demand for high-quality capabilities [14]. In contrast to a variety of other sectors, the construction sector has historically fallen back in terms of technological advancement. As a result, industrial advancements have been insufficient and have continued nearly flat for decades [15]. Construction workers rely heavily on specific abilities, knowledge, technical readiness, and experience-based decisions, all of which are extremely difficult to automate. According to the latest studies, the construction industry has not kept up with productivity advancements in the manufacturing industry during the previous 20 years [4]. The construction and manufacturing industries have a significant gap between them. Even though the construction and manufacturing industries correspond to two separate groups, they are both highly dependent on one another. In light of the development concept of construction industrialization, the construction sector may even be regarded as an exceptional example of manufacturing [16]. The manufacturing industry produces products with standardized processes, but the construction industry is not the same because every project is unique, and although some buildings have the same designs but face different building conditions. Therefore, in the construction industry there is nothing standardized and the construction system is a one-time production system unlike in the manufacturing industry, construction is a very separate process with unstructured operations and a non-linear workflow [12].

During the previous revolutions, it produced information, mechanical and electrical technology, which was intended to enhance the productivity of work procedures. The emergence of the fourth revolution was bound to affect the construction industry, which brought about a revolution not only in enhancing productivity, but in how buildings are designed, built, maintained, and used [17]. The construction industry has been rapidly and effectively associated with fourth revolution technologies such as “augmented reality, drones, 3d scanning and printing, building information modelling (BIM), autonomous equipment, advanced building materials, social media, modularization/prefabrication, internet of things (IoT)/internet of services (IoS), digitization, automation, and last building management systems (BMS)”. Despite the wide variety, this has demonstrated that these revolutionary technologies have reached a point of maturity in the construction sector. Improved project delivery [18], enhanced exchange of information, data-driven decisions [19], cut down on-site accidents and risks [20], and enhanced performance [21] are foreseeable as a result of the implementation of the above mentioned technologies. Table 2 shows the latest technology in the industry and its synchronization with the activities of the construction industry, in addition to clarifying the functional benefits of the synchronization.

For the query "Industrial revolution 4.0" AND "Construction Industry," the analysis started with a wide range of borders to find, appraise, and analyze the published researches to determine the structures and trends. The selected articles suggested that these were the most common fourth industrial revolution keywords, which would be classified into 3 groups, as shown in Figures 1 and 2. Figure 1 displays the highest frequently keywords search in the Web of Science for "Industrial Revolution 4.0" AND "Construction Industry," with a minimum frequency of 3 occurrences. Only 13 of the total keywords met the requirements. The overall strength of the keywords linkages with other keywords was calculated for each of the 13 keywords. Meanwhile, Figure 2 displays the most frequently keywords search in Scopus for "Industrial Revolution 4.0" AND "Construction Industry," Because of the large number of keywords, the frequency of 6 occurrences was chosen, so that we have several keywords close to what was chosen previously. likewise, only the 19 most powerful keywords were chosen from all list of keywords.

Table 2. The technology of industry 4.0 and its synchronization with the construction sector

Technologies	Construction synchronization	Functional benefit
Internet Of Things		
Big Data	Analysis	Promoting Sustainability
Cyber Physical System	Documentation	Increase Productivity
Additive Manufacture	Fabrication	Give Flexibility
Cloud Computing	Construction 4D & 5D	Speed Boost
GIS	Construction Logistic	Better Quality
Virtual And Augmented Reality	Operation & Maintenance	Safe Building
Mobile Computing	Renovation	Improve Working Conditions
RFID	Conceptual Design	Environment Protection
Drones	Detailed Design	Innovative Ability
Nanotech	Monitoring	Cost Saving
3D Printing	Safety	Reduce Risk
Sensors	Planning & Scheduling	Increase Communication
Advanced Robotics		Save Time
Artificial Intelligence		Enhance Decisions
Social Media		Promoting Sustainability
Dashboards		
BIM		

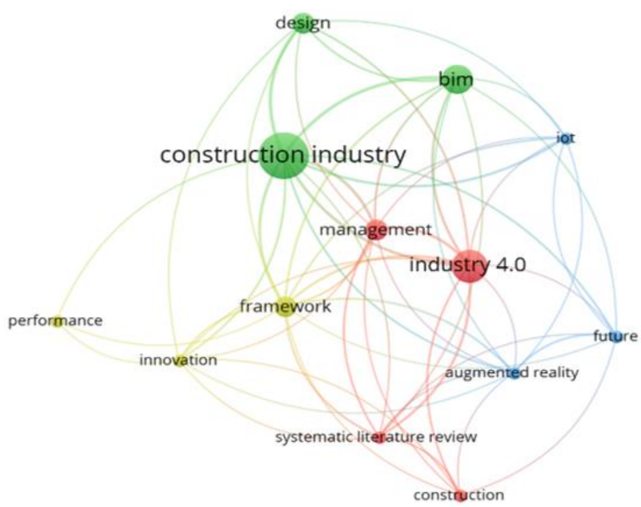


Figure 1. The highest occurring keyword search in Web of Science for "Industrial Revolution 4.0" AND "Construction Industry" yielded 86 papers

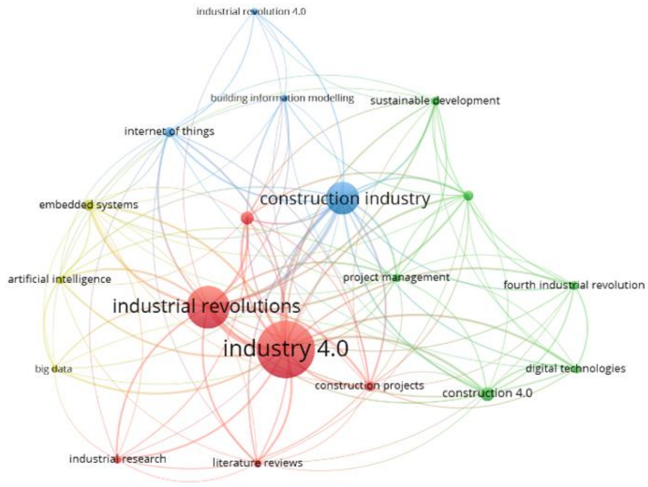


Figure 2. The highest occurring keyword search in Scopus for "Industrial Revolution 4.0" AND "Construction Industry" yielded 122 papers

The intensity of the overall occurrence linkages with other keywords was calculated for each of the selected keywords. The keywords with the highest linkage intensity were chosen. The phrase "co-occurrence" refers to the closeness of keywords in a publication's title, keyword list, and abstract to establish linkages and identify the study topic [22]. The strength of their co-occurrences is specified by the linkages.

Tables 3 and 4 show how the keywords were separated into 4 clusters and ranked according to the strongest frequencies of occurrences from the specific keyword search in Web of Science and Scopus, sequentially. The overall linkage strength of the associated keywords is also represented. Web of Science's top keywords were "construction industry", "industry 4.0", "framework" and "BIM" while Scopus' top keywords were "industry," "application," "internet," "construction," "environment," and "data."

Table 3. The highest occurring keyword search in Web of Science for "Industrial Revolution 4.0" AND "Construction Industry"

Keyword	Group (Cluster)	Occurrences	Total Linkage strength
Construction industry	2	11	33
Industry 4.0	1	8	25
Framework	4	5	23
Management	1	5	19
BIM	2	7	18
Systematic literature review	1	3	14
Augmented reality	3	3	13
Design	2	5	13
Innovation	4	3	11
IoT	3	3	11
Future	3	3	10
Construction	1	3	9
Performance	4	3	3

The conclusion from all of the keyword search results is that the construction industry was strongly linked to the industrial revolution 4.0 in Scopus and Web of Science, which shows how tightly they are synchronized together. IR 4.0 technologies are the new pillars of the construction industry and this link between them is the backbone and the new oil for the future renaissance that will lead the transformation towards the intelligent digital era.

Table 4. The highest occurring keyword search in Scopus for "Industrial Revolution 4.0" AND "Construction Industry"

Keyword	Group (Cluster)	Occurrences	Total linkage strength
Industry 4.0	1	73	168
Industrial revolutions	1	52	150
Construction industry	3	38	115
Construction	1	13	43
Construction projects	1	10	40
Architectural design	2	10	37
Embedded systems	4	11	35
Construction 4.0	2	14	33
Internet of things	3	10	31
Project management	2	8	30
Sustainable development	2	9	30
Literature reviews	1	8	29
Artificial intelligence	4	8	27
Digital technologies	2	8	27
Fourth industrial revolution	2	9	23
Industrial research	1	8	21
Big data	4	7	19
Building information modelling	3	7	15
Industrial revolution 4.0	3	7	9

4. VISUAL COMMUNICATION OF DATA IN THE CONSTRUCTION INDUSTRY

Information is a valuable economic asset, and a lack of it has increasingly been recognized as one of the key causes of many negative outcomes in the literature. Businesses must have extraordinary insights or possess particular information that helps to uncover and explore opportunities to be successful. The information is coordinated and organized data that is of high value and usefulness and allows making the right decision at the right time and circumstance [23]. It's the kind of knowledge that allows you to make fast decisions and rapid progress on a current task or activity. On any construction project, "project information" refers to all of the data, in whatever format, that is utilized to plan, communicate, and execute the project from start to finish. Accurate information and analysis aid in determining the trustworthiness of a possible partner, consumer, or service provider. To provide all of the essential services, construction companies work with a variety of other sub-contractors. The accurate information assists in determining the hazards associated with each operation from conception to completion.

Organizations require information from their environment, whether internal or external, to reduce uncertainty and risks. As a result, research has been carried to demonstrate the value of information. In contrast, Whetsell et al. [24] suggested that information changes organizational perceptions of possibilities and motivates organizational practices that result in positive outcomes. Furthermore, information acts as a control framework, enhances innovativeness and competitiveness, increases contentment, decreases uncertainty by explaining procedures, objectives, and choices, and increases confidence. As a result, a lack of proper information might have a negative impact on enterprises, such as their long-term viability and performance [25]. Table 5 is a summary of some studies that adopted and developed monitoring systems in the construction industry. The core principle of monitoring systems is to transform data into information, to make it useful, and to be able to recognize that data and pull-out value from it. In the table, the previous studies were analyzed and sort them into categories according to the context of the research, clearly can notice that monitoring systems were developed for most aspects of the construction industry, furthermore, the core of the researches study was briefly addressed with the most important keywords were mentioned.

Table 5. Summary studies of some integrating monitoring tools in the construction industry

Research context	Important keywords	The core of the research area	Authors
Health & safety	Risk, hazards, privacy, compliance	Develop a construction risk map, a structural health monitoring system, and a framework for storing and analyzing real-time data	“[26, 27]”
Stage monitoring	Feedback control, stage analysis	Develop a system for information integration	“[28-30]”
Energy monitoring	Saving, consumption, efficiency	Develop multi-technologies integration tool for energy management	“[31, 32]”
Smart monitoring	IoT, BIM, sensors, smart buildings	Develop multi-technologies integration tools for building monitoring	“[33, 34]”
Water management	Water quality, microcontroller, sensors	Develop an intelligent water management system using multi-technologies	“[35, 36]”
Facility management	Sensors, data processing, building life cycle	Develop a predictive integrated analysis tool for the facility management system	“[26, 37]”
Data management and visualization	Information modelling, heterogeneous data, real-time monitoring	Develop a big data management system by integrating multi-technologies	“[38, 39]”
Disaster and emergency response	Unmanned aerial vehicles, wireless sensor, evacuation/rescue route optimization	Develop an emergency response system	“[40, 41]”
Waste management	Solid waste, Environmental impact, Conservation of resources	Develop a construction waste management system	“[42, 43]”
Predictive maintenance	Decision support system, detection, forecasting	Develop a real-time information system for prediction	“[44-47]”

5. DASHBOARD ADOPTION: A REAL SCENARIO APPLICATION OF HIGHWAY GREEN PERFORMANCE MONITORING

The dashboard is a web-based platform that manages the communication link between construction parties. This platform is dependent and runs through the use of Internet technology, which facilitates the flow of information between construction parties. The web dashboard connects many parameters and elements, allowing them to interact with one another and construct the appropriate communications system. During the project phases, this system serves as the foundation for construction industry management and monitoring. According to the data given by the concessioner, each element of the dashboard displays specific information. A web-based conceptual architectural framework can be seen in Figure 3. This figure describes how to use the dashboard to access desired data and information of Malaysia green highway index (MyGHI) and Carbon Footprint Calculator (CFC) easily and simply and can obtain reports as well. For example, if the user choose MyGHI score they can select which concessioner to display and choose the criteria and sub-criteria to see the scores and print reports, same as for CFC. As a result, the presented information for users with various responsibilities in the same web dashboard will be different.

Monitoring and control functions for the dashboard must be considered, to display the important data for real-time monitoring of highway green performance. The monitoring dashboard can handle a large quantity of data while being as simple as possible. Several technologies have been examined and used to achieve this goal. Data is obtained from two evaluation projects, the MyGHI and the CFC, as part of the MyGHI Dashboard project. MyGHI is to measures the level of the greenness of a highway. MyGHI covers the fundamental elements of green highway development that are suitable for the tropical region (Malaysia). Meanwhile, CFC for the Malaysia green highway is to measure the amount of GHG emitted through the combustion of energy represented in an activity. Carbon footprint is the total set of greenhouse gas emissions caused directly and indirectly expressed as CO2e [48, 49]. The dashboard works as a key performance indicator for the green highway performance. Finally, a report generator is used to create reports for every highway performance in the holistic dashboard. Figure 4 shows the dashboard user interface.

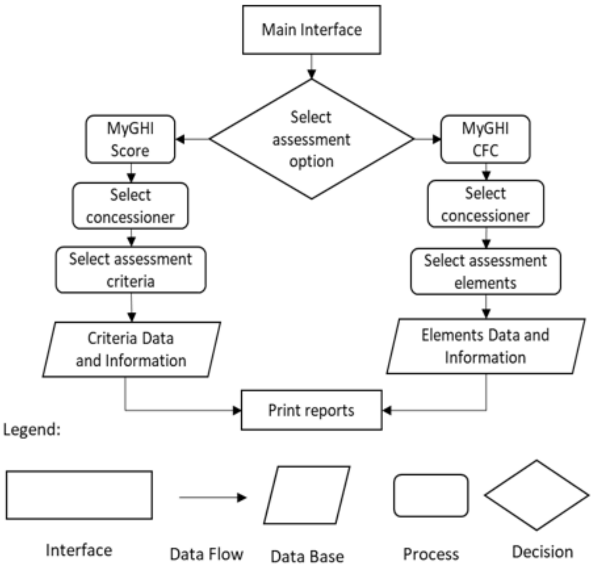


Figure 3. System architecture for the integration dashboard

Figure 4. Dashboard user interface

6. DASHBOARD FUNCTIONALITIES

The dashboard user interface, which was conceived and built as part of the MyGHI project, is heavily utilized for performance management and monitoring. The dashboard communicates with highway concessions to obtain the most up-to-date information on each highway's and concession's green performance. To utilize this dashboard, users must first register in the system and supply some basic information like name and contact information. Upon completing the registration process, users will be given credentials to access the dashboard. The system administrator can indeed specify access levels and permissions for concessionaires, public, government authorities, and stakeholders to manage data supplied and privacy throughout the dashboard. Figure 5 displays the login page of the dashboard.

The specific functions of the dashboard user interface are to allow the users to browse and monitor all concessionary's green performance upon successful registration and logging in. The dashboard visualizes performance information according to various options. To receive comprehensive information from every console, users can move between the dashboard levels easily. Several consoles have been added to the panel so that the user can navigate through display options. The consoles are:

I. MyGHI Score
   a. MyGHI Categories
   b. MyGHI Levels
   c. Concessionaries Report
      1. "Sustainable design and construction activities (SDCA)"
      2. "Energy efficiency (EE)"
      3. "Environmental and water management (EWM)"
      4. "Material and technology (MT)"
      5. "Social and safety (SS)"
      6. Summary Scorecard
      7. Certification Level
II. CO_2 Emissions
   a. Emission Factors
   b. Concessionaries Report
      1. Planning & Design Stage
      2. Construction Stage
      3. Operation & Maintenance Stage
      4. Scope 1
      5. Scope 2
      6. Scope 3
      7. Total Emission
III. Summary Report
IV. Dashboard Framework
V. Guideline
VI. Contact Support

For instance, Figure 6 displays a snapshot of "Sustainable Design and Construction Activities (SDCA)" a main element in the MyGHI assessment index within the dashboard. This page presents the information regarding SDCA and compared it with the Max Score for a specific concessioner.

Figure 5. Dashboard login page

Figure 6. SDCA information page for a specific concessioner

7. CONCLUSIONS

Even though the construction sector, like the manufacturing industry, is the lifeblood of countries economy, its production can be remarkably enhanced by utilizing IR 4.0. The research aims to determine how far the construction sector has progressed in terms of IR 4.0 and intelligentization. The development and progress witnessed by the rest of the industries and the adoption of new technologies support and push the construction industry towards IR 4.0. The research demonstrates that the construction sector is making unremitting efforts and initiatives in terms of evolving and enhancing digital technologies. However, IR 4.0 has certain ramifications for the construction sector. In the last few years, the use of digital technologies in design and construction has matured, and for many organizations, it has already become traditional. Even though in recent years in some countries it has become mandatory and necessary to use BIM techniques in digitizing the construction industry. The gap has been recognized for a long time as a substantial disparity from how the building is designed and is inspected to demonstrate conformity in the virtual world and how buildings operated in actual life. To meet this challenge, governments, industries, institutions, and academic researchers will all play an important role in reconsidering what is needed to build the next generation for future employment.

There are some opportunities to open up some future areas for other researchers who have similar interests. Further research might include extended research with the same approaches to achieve Web-based dashboard for Green Building Index and the Road Rating System. As big data integration is set to influence the industry, the research findings would be a catalyst for creating the much-needed awareness to support the development of big data integration for the construction industry. Furthermore, future research is needed for the examination of these data to be used globally. Lastly, in the future, a continues research on the development of a mobile application to be connected to this dashboard to present a real time data with low cost and efforts on the data collection process.

The major focus of the research was on the principle of IR 4.0, which enables intelligent, economically, productive, customized, and scalable construction at a low cost. With the help of the aforementioned technology, it will create a safe, sustainable and comfortable environment for its occupants, in addition to making the building more intelligent and flexible for the efficient and economical use of resources. The fourth industrial revolution technology is explained and its synchronization with the construction industry to achieve sustainable construction development. The most recent studies that adopted data visual communication tools for monitoring the construction industry were analyzed. These tools have many advantages, including assessing the performance of the construction process and providing the key performance indicators required for construction management and decision support. The term "Industry 5.0" has been applied to areas of research that are thought to be on the verge of a new industrial revolution, but it refers to a more structured transformation that includes effects on society, policies, systems, and human culture, along with looking for new ways to collaborate to enhance production, construction, and process quality. The integration of human intelligence with cognitive technologies is one of the most anticipated advances in Industry 5.0.

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