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Implementation of Digital Transformation Technology at Construction Worksite to Prevent Workplace Incidents and Improve Safety Culture in Construction Industries

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Abstract: *The aim of this paper is to look into the digital transformation of the construction worksite, more specifically to the impacts of Artificial Intelligence for workers and work-environment safety. The scope converges on the more tangible consequences of safety rather than health and focuses on the impact on safety roles and performance as well as implications for jobs and collaborative dynamics between construction organizations. The thesis pushes forward the current state of safety performance and collaborative relationships both in theory as much as in practice and stresses the shift of performance measurements and success factors for the former as well as the roles and goals for the latter.*

The construction sector is a considerable contributor to a country's economy. For example, there are more than 300 000 people employed in the construction sector in INDIA. Unfortunately, workers' safety is a big problem in this high-employment sector since the potential risk for injury is high. In INDIA workers in the construction industry are among the most injured, both in terms of work-related accidents and occupational injuries. With more technology advances, there has been an increasing interest in the construction sector regarding new technologies in recent years which also includes occupational safety and health technologies.

The results provide a list of different types of safety technologies that have been investigated previously and a versatile overview of safety technology's development process, adoption process, and facilitators and barriers for a successful adoption.

This study points out the benefits of utilizing safety technologies and provides extensive information regarding the adoption of safety tools, that could encourage engaged actors in the field to strive for more safety technologies which could lead to a safer work environment and healthy worker.

Keywords: Digital Transformation

I. INTRODUCTION

The rise of digital transformation (DT) across all industries has deeply taken root in today's incremental progress and advancements with the arrival of technological revolutions such as digital twins (Panetta, 2019; Edirisinghe, 2019), (Agarwal, Chandrasekaran and Sridhar, 2016), Artificial Intelligence (AI) (Agarwal, Chandrasekaran and Sridhar, 2016; Polyanin et al., 2019; Alsheiabni, Cheung and Messom, 2019) and the globally data-oriented focus they have enabled. So much so that authors Polyanin et al. (2019) have inferred that human society is undergoing a digital industrial revolution as a result of the fast-increasing processing power and massive data sets which feed ever more complex algorithms (Panetta, 2016).

Conventionally, the construction industry has opted for slow and incremental advances due to its volatile and unique nature (Zhou, Goh, and Li, 2015) which makes for specific project-based technological and processual improvements difficult to scale up to an organizational level much less to an industry level (Agarwal, Chandrasekaran and Sridhar, 2016; Costello, 2020). Nonetheless, the construction industry is one that is lagging behind its other counterparts when it comes to its digitization levels (Agarwal, Chandrasekaran and Sridhar, 2016; Motawa et al., 2007; Edirisinghe, 2019; Bosch, 2020).

II. BACKGROUND

The concept of Artificial Intelligence (AI) has long existed in myths and stories and yet the term AI was first used in the mid-twentieth century (Eber, 2019). AI has been received differently over the course of time. Starting around the 1950s with Alan Turing, developing his deciphering machine called The Bombe while simultaneously in another part of the world Marvin Minsky started uniting interested scientists from different fields, aiming for a human-level intelligent machine, Artificial Intelligence underwent a golden age with significant progress until the 1970s when it began to widely receive criticism which consequently eliminated funding for AI projects in both UK and USA (Haenlein and Kaplan, 2019).

After the AI winter, which was associated with lesser if not no funding on AI projects and infamy of anything related to AI, the enthusiasts of the field arose to continue on exploring the field (Haenlein, and Kaplan, 2019), this time with more support from available technology (Taulli, 2019). Advances on technology such as increase of dataset, improved infrastructure and invention of GPU accelerated the growth of AI research and implementation (Taulli, 2019).

2.1 Aims / Purpose of the Study

As the introduction briefly presents, the main purpose of this paper is to first, analyze current theoretical approaches and trends towards the organizational digital transformation of the construction industry incurred by AI (machine learning) and more specifically for the management of occupational safety. Considering the burst of Machine Learning deployment in different industries, including construction, the near future seems to be widely and deeply affected by new tools that AI is putting at disposal. As future construction managers, it comes as a necessity to understand, prepare, or be prepared for the possible outcomes and challenges brought forth by the construction industry, i.e., how to understand the evolution of jobs, the meaning of safety performance and safety solutions, the implications of collaborative dynamics.

2.2 Historical Background

The fourth industrial revolution – also known as the industry 4.0 paradigm – brought with it an entire new level of optimization and automation of its previous digital era by adding the intelligent networking of machines, processes, and people [1]. One important characteristic of industry 4.0 is the exploit of modernized tools to interconnect the data coming from different parts of the system including the machine unit, the product, and the people [2]. Such tools are the basis of this current industry, and they are formed by cyber–physical systems (CPSs), Internet of Things (IoT), cloud computing, artificially intelligent systems, and cognitive computation .

This allows it to be a self-learning system utilizing data gathered from a variety of sources, including sensors that convey operating conditions, from specialists, like engineers with in-depth understanding of the industrial domain, from other groups of similar machines, in addition to incorporating historical data [7]. This motivated companies across the globe to start investing and adopting the use of Digital Twins in their industries as a way to achieve finer results and increase the competitive advantage of their services [8].

Nonetheless, with these increasing technologies and with less focus on safety part of processes, the occupational health and safety management was struggling to keep up with such revolutionary steps [9]. This was due to the lack of modernized tools also in the safety management practices. Consequently, there has been a sharp rise in accidents mostly in the sector of manufacturing and construction where industry 4.0 had the highest impact. From here came an additional question on whether we can use the same technologies that promoted advancements in certain industries, most precisely DT models, to adopt them in safety management procedures and upscale the level of readiness of workers in case of mishap pens in the workplace.

2.3 Objectives

This paper aims to investigate the use of Digital Twins in present applications to satisfy safety management purposes while serving as a wake-up call for stakeholders of high-risk industries to invest in such applications, which are found in literature and accumulated in this work, so to ensure a safer workplace for their employees. Moreover, there will be an elaboration on the models and methodologies that are adopted or are currently under study which satisfy modern safety needs from the point of view of the Digital Twin technological aspects. And finally, a discussion will be developed on the level of effectiveness and simplicity for companies to include such Digital Twin models to conduct risk models and develop safety trainings at complex workplaces.

2.4 Scope

The scope of this paper is focused on the investigation of the direct relation of how Digital Twin Technology could support Occupational Safety and health Management and provide solutions for stakeholders to act fast in the face of the high-risk technological advancements

III. LITERATURE REVIEW

3.1 Digital twin concept

To shift from the predominantly paper-based and manual product data, there was the need to pass to a digitalization side of models. From here came the concept of Digital twin which was originated from the works of Michael Grieves with John Vickers in 2003 on product life-cycle management As Grieves provided the first characterization of the Digital Twin concept, he stipulates that it has three main corners, a real physical product, a virtual representation of that product, and the connections of data and information that link the virtual and real products together.

Since the original concept of Grieves two decades ago, there has been an emergence of a variety of definitions for the Digital Twin due to growing interests and wide applications, which in turn obscured its original description given by Grieves.

3.2 Recent Implementations

To demonstrate the diversity of conceptual backgrounds, approaches, and scopes of the Digital Twin technology, it is relevant to present the different application scenarios coming from different sectors. This is interesting so to further understand how the same technologies could be put into use for safety management purposes. The highlighted sectors in this section range from applications as delicate as structural components , construction purposes and goes all the way to smart cities . These topics will be discussed briefly at first as to drive the focus on safety management in the second part of this section.

3.3 Safety Management

Even though the development of DT applications in the construction and manufacturing sectors has lately received more attention, there are still interests in using similar technologies to promote industrial safety.

There has been development of interesting studies previously for Digital Twin for safety management purposes dealing with predicting high-risk scenarios, risk assessment and sensitivity evaluation to critical disturbances. However, these models could not adequately refer to Digital Twins since Industry 4.0 theories started in 2011, and they were defined in 2013. Instead, these papers address broad simulation models for maintenance or safety management.

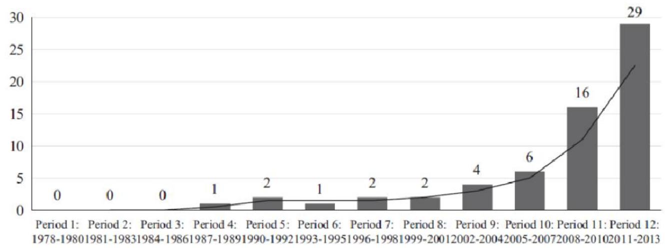

Figure 1. The course of innovative technology practices in construction safety as presented by [9].

In 63 studies, a total of 21 different types of advanced technologies (such as Building Information Modeling, Geographic Information System, Remote Sensing, and virtual reality) were taken into account for construction safety management. Nevertheless, the majority of these innovative technological applications are still in the academic research

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stage and do not correspond to Digital Twin technologies as well [9]. As a consequence for construction safety management, let alone industrial applications on a wide scale, new DT technological applications have hardly ever been practiced for safety purposes in the early stages of DTs.

3.4 OSH Management

1. Major accidents in health management

Throughout the years and until present time, there are continuous occurrences of tragic events that take place in workplace environments causing economic losses but more importantly human fatalities. These incidents take place mostly in the manufacturing and construction industries as reported by Cheng and Wu (2013) [17], and [18]. And even though it only employs 7% of all workers worldwide, the Architectural Engineering and Construction (AEC) business accounts for 30–40% of deaths [9]. According to census statistics from the U.S. Bureau of Labor Statistics (BLS), a total of 774 individuals died in the United States in 2010 as a result of accidents they sustained on construction sites, making up 16.5% of all industries [19].

2. OSH Management Key Elements

The foundation of the principles of OSH and risk management is the adoption of a health, safety, and environmental (HSE) program, which have as a main objective the safeguard of a company's assets from unintentional losses due to accidents [21].

The system elements that must be managed consist of, among other things: (1) the health and safety of workers, vendors, contractors, customers, and community members (e.g., improvement of public health and safety); (2) the safety of goods and services, materials, equipment, work systems, and plants; (3) integrated pollution control, radiation protection, waste minimization, recycling, and waste disposal; and (4) integrated waste management of natural resources with the reduction of activities that use nonrenewable energy.

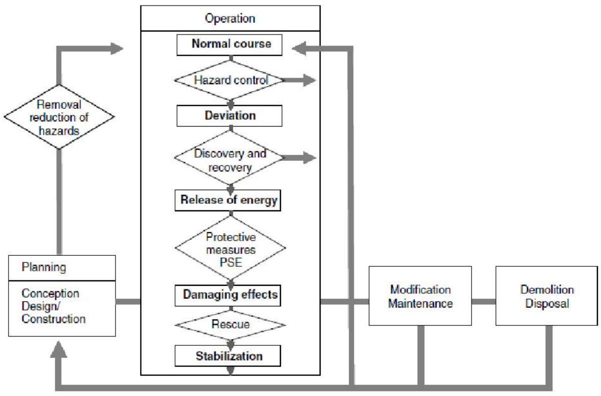

Figure 2. Risk assessment and effect management through the life cycle of business activities presented by [21].

The cycle is based on the ISO 14000 environmental management standard and the BS 8800 OHS management system standard.

Interestingly, the activities of risk assessment and identification are the pillars or the base where Digital Twin applications start. It can be noticed in the following chapter, that the methods used by DT act precisely in this context, only with further cutting-edge tools, using cloud computing, logic networks and virtual reality games.

IV. METHODOLOGIES AND PROCEDURES: CURRENT AND PROPOSED TECHNOLOGIES

As already discussed, the Industry 4.0 can implement autonomously controlled, data-based, and sensor-equipped machinery and equipment that enhance operations through self-optimization and autonomous decision-making. This revolution will fully automate and digitize production at workplaces.

However, the diversity of subjects and the number of papers considering Industry 4.0 technologies, including DTs, made it challenging for enterprise managers and practitioners to discover their use for safety management purposes and have extensive details on methods that might help in solving key-issues in their business' occupational health.

4.1 Real Time Monitoring

With the introduction of the digital twin in smart factories during the Industry 4.0 era, sophisticated technologies may be used to link safety processes with autonomous monitoring systems for risk prediction and prevention. Employees working in hazardous situations in which they might be exposed to severe heat, poisonous fumes, ignition sources, or harmful materials and chemicals may benefit from monitoring devices such as sensor-embedded helmets and wristbands [23].

In order to provide cloud-based tools for safety evaluation in a working environment, [24] introduced a Kafka-based architecture that blends inertial data acquired from wearable devices with human postures derived through inference from RGB-Depth cameras.

I. Prior accessing the assembly line, the employee is given a worn gadget with an inertial measurement unit (IMU) linked to the Jetson board through Bluetooth Low Energy (BLE).

II. A 3D human posture estimation (HPE) algorithm is engaged when the wearable is shaken in front of the RGB-D camera, and the wearable's unique identification code is linked to a collection of 3D key points that depict the joints in the human body, effectively reconstructing the human skeleton.

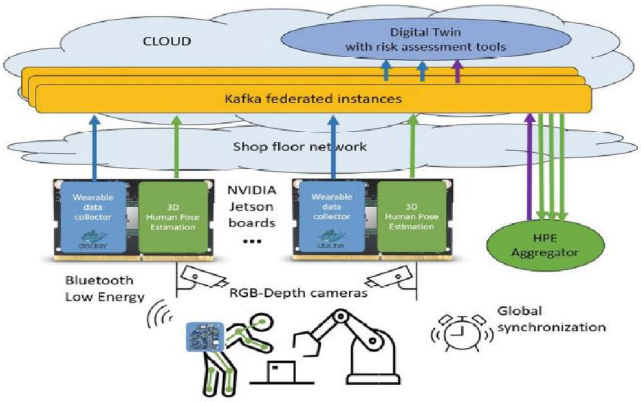

Figure 3. Architecture overview of the system discussed by [24].

Because risk assessment takes less time under the suggested approach, organizations may perform the risk assessment studies at a lower cost. Given this competitive advantage, the aforementioned method appeals not only to major corporations but also to small and medium-sized businesses that are seeking to enhance the working conditions for their employees [25].

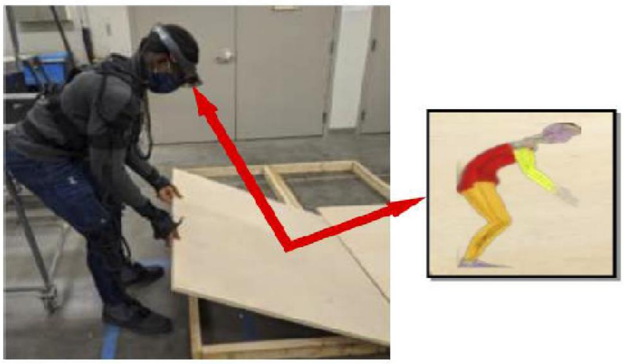

Figure 4. Task of setting a board (left) and a view of a digital twin (right) represented in [26].

Additionally, self-aware and self-learning machineries equipped with advanced DT analytics may well be capable of monitoring and predicting dangerous situations during workplace activities and use prognostics and health management algorithms to handle such unforeseen conditions, preventing accidents and injuries to both the employees and bystanders [23].

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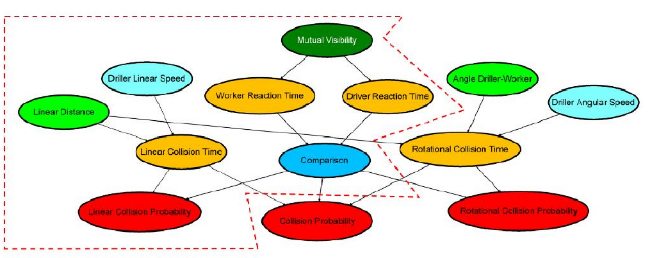

Figure 5. The Bayesian network developed for the collision risk assessment proposed by [19].

The result as [19] states, is an AI technology that monitors surroundings and computes in real-time the collision probabilities during construction operations, hence, its goal is to increase workers' awareness in order to avoid injuries and fatal events in the work site.

Therefore, by providing real-time monitoring and continuous assessment of risk levels, DT can greatly benefit OHS management not only in construction sites but also in any high-risk environments including manufacturing workshops. Since these immerging solutions are becoming present at relatively low prices, it is now up to employers and organizations to make the call and start adopting such methods; consequently reducing labour harms caused due to lack of innovative safety management methods.

A proposed model for process plants

In the following, a proposed reference model by [7] to reduce operator's risk in process plants has been reviewed and summarized.

The authors of this model claim that the latter allows companies to: (i) create a virtual workflow that runs concurrently with the real one; this virtual process will serve as a tool for both static and dynamic assessment of the physical industrial process; (ii) spread this information to other integrated and realizable digital objects to enhance the safety of the involved actors; and (iii) interrupt malfunctions at the early stage to be able to act quickly to avoid further damage or assist preventive/predictive measures.

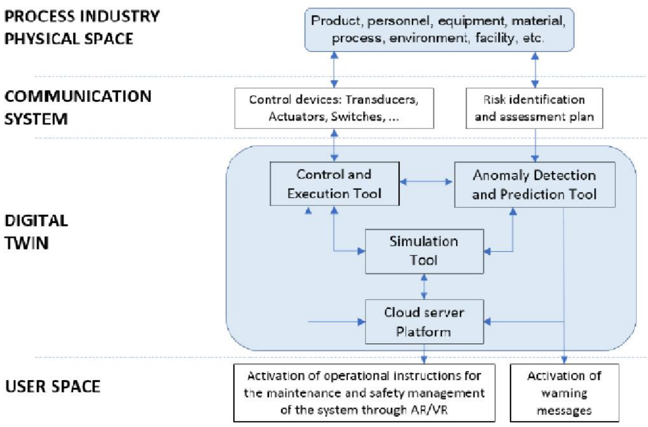

Figure 6. Digital Twin Reference Model adopted by [7].

The phases and their implications are recapitulated as follows:

1. The process industry physical space layer, which contains the physical assets that the company aims to regulate.
2. The communication system layer, devoted for transferring information between DT and plant components.
3. The Digital Twin layer, responsible for data acquisition, visualization and analysis, anomaly detection, management of alerts and maintenance support.
4. The User Space layer, offering users AR/VR technology for deployment of maintenance and safety management instructions in addition to triggering of warning messages.

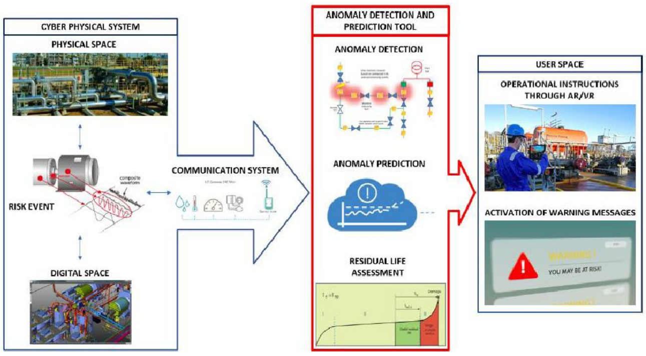

Figure 7. The rule of the Anomaly Detection and Prediction Tool asserted in [7].

Moreover, there are five phases to develop the Digital Twin model as discussed by [7] and which can be noted in figure 8.

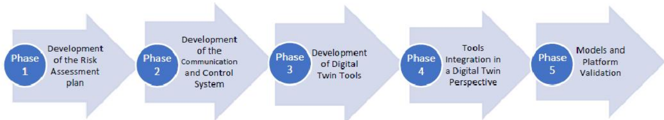

Figure 8. Implementation phases mentioned in [7].

- Phase 1: Development of the Risk Assessment plan containing risk estimation, risk analysis and risk weighting.
- Phase 2: Development of the Communication and Control System responsible for the recognition of the major influencers and the connection between the digital and physical components of a digital twin.
- Phase 3: Development of Digital Twin Tools where machine learning algorithms are employed for anomaly detection and prediction.
- Phase 4: Tools Integration in a Digital Twin Perspective for data gathering and processing, status detection, health evaluation, scenario forecast, and synthesis of recommendations.
- Phase 5: Models and Platform Validation entailing the validation of the platform's capabilities and testing procedures to assess the effectiveness of the approach and determine the key benefits, paying special attention to the advantages in terms of operator safety.

V. EXPERIMENT

METHODOLOGY

This section of the paper aims to demonstrate the meticulous process of data collection and its various sources with regards to the deployment of Artificial Intelligence in safety management. Given the brief introduction in previous section, the thesis researches the added value of AI for worker and work environment safety, and for this the abduction method is applied. That is the study's aim is to provide a reasonably sound inference and exploration on the concepts from the pre-established research question and sub-questions. In other words, in starting with research questions the study sought to acquire secondary and primary data for abdicative reasoning.

Finally, it is important to point out a specific set of key methodological change. First, the layout of the methodology follows the chronological steps of the thesis rather than by order of importance. Second, the thesis study and scope were undertaken without the support of a company and the scope designed and finetuned by the author students. Lastly, the authors denote the shift of the methodological section prior to the theory after the unanimous opposition feedback concerning the importance of the following information towards grasping a better understanding of the theory and hence, the thesis in its whole.

VI. RESEARCH APPROACH AND DATA COLLECTION

This part focuses on data collection methods and as mentioned above, it starts with secondary data collection for chronological reasons and later moves forward to primary data collection.

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QUALITATIVE

The main objectives of the qualitative research are firstly, to diagnose the current state of the issues and developments with regards to occupational health and safety and AI. In keeping with Naoum (2013), the data gathered in qualitative research can be classified under two categories of research which are Attitudinal and Exploratory research.

As aforementioned, the collection of primary qualitative data will be achieved through the use of semi structured interviews. The reasoning behind the choice of a semi-structured interview is primarily due to its comprising of 'open-ended' and 'close-ended' questions which enable the researchers to undergo both attitudinal and exploratory researches on each of the interviewees. Secondarily, because the main strategy behind a semi-structured interview will be to build a rapport with the interviewee in order focus on the respondents' experiences regarding the situations under study (Merton and Kendal, 1946, cited in Naoum, 2007), which in consideration of the population sample and the primary data collection timeframe is of the essence to provision reliable data. The attitudinal research participant-focused questions in the interview will help establish hypotheses, hunches and relations between key issues/enablers present in the field of sustainable delivery of construction projects in developing countries. The exploratory research, however, enables the development of one – or two – specific theories based on the hypothesis and hunches established in the attitudinal research.

STUDY TIMEFRAME

For this particular study timeframe, the researchers have agreed upon a cross-sectional study; it will represent a 'snapshot' of the events and current state of the field. A longitudinal study timeframe, while providing a more in-depth data collection for the formulation and development of theories and hypotheses will not be reasonable for this particular research paper considering the current timeline.

SAMPLING AND STUDY POPULATION

According to Robinson (2014), in a qualitative methodology sampling is an important step and should be accomplished considerately. A sample universe should be defined by common criteria found in the samples. By increasing the inclusion criteria, the sample universe delimits, and the homogeneity increases as well. In this thesis sample universe was primarily bounded to the actors in construction as well as the ones in the AI solution provider companies which are directly connected to construction industry. The chosen actors in the construction should have some experience within health and safety while the solution provider should have some clients in construction industry in order for the interviews to best serve the subject at hand. Due to novel nature of this thesis, the authors decided not to enclose the sample to geographical boundaries but to use the diversity to enrich the analysis. Keeping this in mind, this thesis benefits from the heterogeneity of the samples since the research question addresses a challenge in the industry at its very early stage.

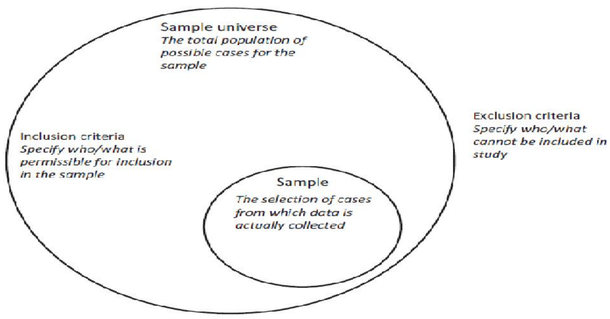

Figure 9 - Sample Universe and inclusion/exclusion criteria (Robinson, 2014)

Due to the level of the research (graduate), the accesses to a panel or a professional database are indubitably ruled out. The questionnaire sought out an audience definition chapter which defined relevant population variables (Dependent Variables) such as: country of origin, level of education (student/professional), years of experience for either the design or construction phase. In order to guarantee appropriate data collection for the qualitative research, the participants will be handpicked according to their respective involvement in safety management with based on the researchers' personal networks acquired during previous and current professional and academic experiences.

INTERVIEW STRUCTURE RATIONALE

Granted, this section might seem to be less clear to the audience as a result of the decision to shift the methodology before the theory. Nonetheless, the overall choice for its move remains justified as per the section's introduction. If necessary, returning to this heading of the methodology ensuing the reading of the theory would help better understand the structure and intent of the interviews.

This being said, the interview structure is defined in two options and both options are divided into three parts. Option A is destined to interviewing a construction industry worker with AI for safety experience during the construction phase; Option B is aimed at construction workers involved in safety for the worksite with either AI experience pre/post construction phase or no AI experience altogether. At the start of the interview, the participants will be asked a series of 4 demographic questions (D1-D4) [Please refer to Appendix A for the interview template as well as the transcripts]. During this demographic conversing, the key areas to point are the provision of anonymity to the participant should they wish it, also a question pertaining to the extent of the working experience in the area of interest. This section helps first, break the ice, second, set out for comfort zones of improvised questions based on the participant's knowledge pool and third, provides a sound background for analysis of the further data. Moving onwards, the interview rationale section will delve deeper into the questions and the sourcing, reasoning and predictive analytical intentions behind them.

The third section, or blue section of the option 1 delves deeper into hypothesis B by covering B(i) and B(ii) which are the impact of AI on business as usual; more specifically, job evolution. The first question 3.1 investigates the performance and capability of safety on-site before and after AI deployment by attempting to acquire direct empirical information from the participant. Ensuing this, the blue section shifts to a "semi" open-ended question that is that they are still angled towards a specific set of information and theory discussed in the literature review.

More specifically, 3.2 aims to acquire pure raw empirical data on the subject of new jobs, responsibilities and roles that are to come for safety on the construction with AI to make for a robust and interesting discussion. Also, it is in the interest of the thesis's analysis to compare and contrast the thoughts of the participants on the upcoming jobs between option A and option B. Finally, the interview is put to an end with a grey section that are open ended conclusive question that are to be asked only if the above question weren't as fruitful as expected or if there is still time left in the allotted interview schedule.

VII. THEORETICAL FRAMEWORK

This section focuses on providing a theoretical framework on the relevant subjects in and around the research question. It comprises of three subsections to set a comprehensive ground for the later discussion as well as building the necessary basis for further structuring of the primary data collection. The first subsection in the following pages provides a basic understanding of the elementary concepts about new technologies (with a focus on Deep Learning in AI). It is, however, important to denote that this section serves mainly to address the technologies that have radically changed other industries as well construction. The aim behind this theoretical knowledge is to present notions that are not commonly understood in the construction sector but rather other sectors.

VIII. NEW TECHNOLOGIES – 3D-MODELLING (BIM), AND ARTIFICIAL INTELLIGENCE (AI)

Overall, automation for construction (safety) offers many similar benefits observed in the manufacturing and industrial sectors whereby these automations provide shorter construction processes (Kothman and Faber, 2016; Tajeen and Zhu, 2014), reliability in operations, new functionalities and personalization freedoms (Loonam et al., 2018). As per the introduction, authors Polyanin et al. (2019) have shown the student writers how human society is currently undergoing a digital industrial revolution.

3D modelling - BIM

During the 1970s and 1980s many aerospace and aeronautical companies such as the French company Dassault Aviation with its original Dassault Systems modelling software for example pioneered Computer-aided Design (CAD) 3D modelling and improved their own productivity tenfold (Agarwal, Chandrasekaran and Sridhar, 2016). Although there has been many other software and companies e.g. ArchiCAD or Autodesk that have contributed to what is now known as CAD. Since then the automobile and healthcare industries have successfully adopted and applied CAD processes as well as its associated benefits even though this is the source of debates in the respective field of study which will not be addressed for this thesis.

ARTIFICIAL INTELLIGENCE (AI)

AI's furthermost aim is to automate, mimic and even outmatch the natural intelligence (Hippold, 2019) which is already achieved to some levels in many logical fields, specifically with the use of machine learning (ML) and neural networks (NN) methods – two of more commonly used AI elements described in detail below – to enhance and empower tasks in different industries and even the construction (Eber, 2019). Although, as a part of Smarter with Gartner research, Hippold (2019) discarded the notion that AI operates alike a human brain as the first and foremost common myth associated with AI, arguing that albeit some forms of ML, more specifically image recognition, outperform most humans, in general they are not equivalent to a human brain performance just yet.

SAFETY MANAGEMENT

Over decades, workplaces have been the ground for accidents leading to an injury or undermining a worker's safety whose cost not only is limited to economic costs but also social and human costs. Occupational health and safety or used interchangeably, Occupational Safety and Health (OSH) is defined by International Labour Organization (ILO) as follows: "...the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities and the general environment" (Alli, B., 2011, p.vii). According to International Labor Organization, aka ILO's illustration of risk, a potential hazard combined with exposure brings the risk. The objective of occupational safety and health (OSH) is "the management of the occupational risk" (OSH management system, 2011, p.1) which is achieved by a thorough risk assessment and preventive solution provision.

Maintaining a safe workplace also contribute to the measures of sustainability in a company. Considering sustainability as a movement to "preserve the societal, economic and environmental systems" (p.3), it inherently includes the wellbeing of human beings which gets explicit in the UN sustainable goals; "decent work and economic growth" and accordingly, providing a safe workplace for workers. Contemplating on the notion of occupational safety composing a part of social aspect in sustainability, this could enhance the involvement two groups. On one side, it makes the sustainability-focused attempts to turn a head toward OSH and in the same manner, the involved people in occupational safety to take a step out of the traditional mindsets (OSHA, 2016).

Safety and AI

The vast amounts of safety data produced by each project in construction industry, is too grand for any individual to analyze on their own – let alone given the fact that a safety inspector can have up to 10 construction projects simultaneously (CIOB, 2017b). This is where AI can come into play and shoulder the analytical and process role (Panetta, 2017). As AI delivers the potential to disrupt business as usual, organizations are turning more attention to it (Panetta, 2017; Costello, 2020; Agarwal, Chandrasekaran and Sridhar, 2016).

As introduced above construction industry is known to be the main responsible sector for work environment injuries and accidents notably in USA (OSHA, 2018) and Europe (EU-OSHA, 2019; European Commission, 2012). The number of fatal accidents in construction surpasses the rate in other industries. According to (Mahalingam and Levitt, 2007, OSHA, 2018, European Commission, 2012 cited in Edirisinghe et al., 2014a), while only 7% of workforce in the world are employed in construction sector, yet the fatality rate is one third of the whole fatal injury in all industries. Bearing the mentioned numbers and ratio in mind, the construction industry calls for a more effective safety management practice which can help reducing the statistics (Winge, Albrechtsen, and Arnesen, 2019). An increased consideration about the accidents resulted in an increasing number of researches forming around the concept of health and safety management in construction.

Trends and early stage examples

As per what was mentioned earlier, in AEC industry, the pace of change toward adaptation of innovative technology is sluggish yet the increasing awareness of its benefits (Zhou et al., 2015) and the swarming influence of these new technologies on other industries, constantly pushes the industry forward to more deployment of them. An overview on research carried out in safety management in construction industry (until 2013) shows a quadrupled number of researches on innovative technology applied on safety in construction industry under a 3-year period between 2008-2010 compared to the 2002-2004 period. The number from the 2008 to 2010 period doubles in the next three years (Zhou et al., 2015).

Past developments in the field of AI for Construction workplace safety sought out to process real-time information from construction operations and processes to track and analyze data related to material, people and equipment (Weiming et al., 2010). According to Nath, Behzadan and Paal (2020), while computer vision and deep learning techniques enabled opportunities for tracking PPE on site, most cases only focused on detecting hardhats. Although there are very few examples in which the detection goes beyond hardhats, such as Smartvid which provide a software for safety vests, goggles and gloves aside from the hardhat (Nath, Behzadan and Paal, 2020). The need for this data processing to be streamlined is ever more present in light of the above-mentioned numbers but also because sites are gradually getting more crowded, where many different activities are undertaken simultaneously.

DIGITAL TRANSFORMATION (DT)

The rise of the digitization era driven by a widespread of methods and tools, such as AI which instigated a digital transformation (DT), turned around most of the industries (Alsheiabni, Cheung and Messom, 2019). In the midst of this era, it could be argued that the construction industry has no choice but to undergo a transformational change (Loonam et al., 2018) for which improved automated evolutions become the norm and the associated processes are fundamentally transformed (Bosch, 2020). Authors (Koscheyev, Rapgof and Vinogradova, 2019; Loonam et al., 2018) surmise that DT is a key success factor towards delivering organizational competitiveness and development.

VIII. DIGITAL TRANSFORMATION OF SAFETY MANAGEMENT IN THE CONSTRUCTION INDUSTRY

Living in an age of digitalization makes it inevitable for companies, organizations and industries to change (Guo et al., 2017), yet the construction industry has proved to be less adoptive or inclined toward change. This could be a result of its “unstructured and changing environment” (Zhou, Goh and Li, 2015, p.343/7) which consequently brings difficulties for implementing a new technology in the exact same conditions for two projects (Zhou, Goh and Li, 2015).

History

According to the literature overview carried out by (Guo et al., 2017) on digital technologies in construction safety management, there are several fields of technologies being used in safety management in construction. He recognized 15 technologies, including BIM, augmented reality (AR), virtual reality (VR), game technology (GT) and real-time hazard management. It is worth mentioning that the literature review is done regarding the published literature between 2002 to 2015 which considering the continuously increasing pace of technology advancements, a different rate in use of these methods are expected as well as the emergence of newer technologies (Guo et al., 2017, Winge, Albrechtsen, and Arnesen, 2019).

Current situation

The above-mentioned technologies increase the efficiency and effectiveness of different safety management systems. For instance, BIM, VR and AR enhance the safety planning by analyzing and determining the expected risks even before the construction starts, i.e. during the design phase which facilitates avoiding the possible safety-related issues less costly (Zhou et al., 2015).

Another example on current use of digital technologies lies in applying a real-time hazard management (Carbonari, Giretti and Naticchia, 2011). According to Guo et al., (2017) in this method which uses location recognition and proximity warning proved to be extremely beneficial for enhancement of safety on construction sites since it enables the safety manager to track not only the trucks but also materials and workers. With a hindsight to the compelling and unstable situations on-site, this method comes to help worker to grasp a better awareness in real-time and be noticed by different means in a shorter period in contrast to potentially limited knowledge based on their experience and estimations or the stationary training sessions (Guo et al., 2017; Edirisinghe et al., 2014a).

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Prospective uses / pilot projects the ("future")

With the arrival of the construction site of the future, wearable smart textiles, or e-textiles, have made for strong developments in the field recently (Edirisinghe, 2017). Current (pilots) and prospective uses of technologies developed for construction workplace safety deployment which do not necessarily involve AI today but could most likely call for it as a part of their role for the construction site of the future are listed and discussed hereafter.

In general, there are several applications of wearable bands/terminals (Agarwal, Chandrasekaran and Sridhar, 2016) on the forearm notably (CIOB, 2017a) which serve to automate alerts such as when operators fall asleep, idle time on the managerial side (Fig. 6). Still, these technologies seek a bidirectional communication and information sharing system whereby the "online operator" (CIOB, 2017a) will be given in real-time guidance, information and help (Edirisinghe, 2019) as a part of the hands-free communication system developed by SUEZ and Bouygues Construction (CIOB, 2017a).

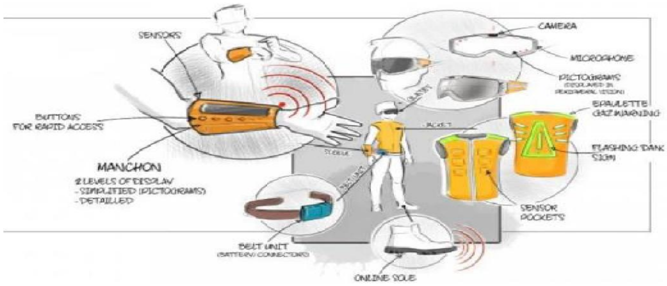

Figure 10 - 'The online operative' Image courtesy of Bourges (CIOB, 2017a)

On a final note, author Costello (2020) stipulates that "launching pilots is deceptively easy but deploying them into production is notoriously challenging" which should be bearing in mind when considering these future technological applications for construction safety. Parallelly, while there is an array of academic research and content on the developments of future technologies for the construction site, very few consider the human viewpoint these entail, that is to include those concerned in the development and application of said technologies (Edirisinghe, 2017) which is a point the thesis will look into for the empirical data collection.

ANALYSIS

This section moves forward to the findings and thus analytical part of the thesis where the verbatim qualitative data from the interviews executed for the research. As per the methodology above, the interview participants fell into two general categories and two subcategories: academic & professional and construction & AI experience and/or knowledge (See Figure 7). Although the interview participants did not wish to be kept anonymous, they will still be given fictitious names for the entirety of this analysis and discussion albeit their information and details figure in their respective appendices.

QUALITATIVE RESULTS

The results in this section is divided into two sections; first part is the results acquired from the academic sub-group and the second one is focused on the results from the professional group. Bearing in mind that the interviews started with the demographic questions which has been brought up in the previous section as a preview to the interviewees.

Yellow

This part starts with a question about the project they are involved with and its contributions. Richard is knowledgeable in the available AI applications and software developed and its use for safety and as a part of his consultancy job. Helena is in rather starting phase of her research which evolves to be a machine learning model which can identify risks corresponding to accidents. She claims that she attempts to involve safety engineers to work with finding and evaluating a solution for risk identification.

Anna answers to the same question by introducing the Smart Built Environment program extensively, mentioning that the program is aiming to provide more sustainable ways in construction by examining the processes, methods and technologies. The borders of the project start from design phase and even before; the construction permissions and

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stretches further to construction site and they are looking more into technology recently, more precisely, discussing the innovative uses of AI within construction with AI Innovation of Sweden. John who is the Machine Learning engineer explains about their project as one of the pioneers in this area. Smartvid, based in Boston, USA, provides construction companies with a web-based and mobile-based app which analyze the visual data sent from construction sites. The app is used for health and safety as well as monitoring the progress of the project.

Later on with the question about dynamic and collaboration among the internal actors in the project during implementation, Richard answered the main factors involved are H&S managers who decide and apply the AI model to the project and the workers on the site are mainly involved during training for H&S and they are only informed of the solution being used, for instance the cameras collecting data from the site. He further states that they may later get feedback in case that hazardous situations happen but in general he finds it unconventional to talk about it with the lower part of hierarchy. In case for Helena, as she mentioned under previous answers, they involve the safety engineers in the company from the beginning to the prototype and until the final product, but the involved actors' dynamic and presence goes further to an AI specialist, a head of AI division in a university, who in collaborating during the meetings with companies who has taken interest in the project. She mentions a co-supervisor as well who is specialist in machine learning. The two AI specialists, she mentions had previous interdisciplinary experience yet not in the construction industry, but they are helping with development of the model as well as choosing the algorithm and other technical aspects. It seems that there are two type of actors involved, the ones in closer and constant connection such as the AI developer or the strategic health and safety developer in the main company, as opposed to those with biannual meetings which includes the representatives from other interested companies.

Green

When questioned about the knowledge sharing and collaborating, the participants were all using a negative perspective and turn of words. Still, it is Richard and Helena who were most adamant about the 'difficulty' surrounding this topic. Helena argues in her case that the data in itself was very unstructured and difficult to work with. On the other hand, Richard (Appendix E) certifies organizations have no incentive to share their information with others. Despite the added complications of getting all identifiable filmed or photographed people's authorization no one is willing to take the risk of divulging such information he states. Ironically, he also concludes his thought by claiming an organization would benefit from a system with other willing organizations' shared knowledge.

Nonetheless, both the practice and academic sides concur on the relationship being initiated by the construction organizations. Anna says this is perhaps because they are more established and have a development manager or such roles in the small flexible organization structures. This comes of interest when juxtaposed with Richard's rather descriptive comment regarding how some technologies are just 'smart people trying to shove it down the throat of construction people; "you got to use this it's going to help" (Appendix E). Thus, implying these external solutions to internal problems seem to just look for the problem rather than solve it.

Finally, this topic concludes with an open-ended question asking the participant to surface any problematics with today's current operations and methods between construction and AI organizations. Richard, with 20+ years of research in construction innovation stamps construction as being very stagnant and then there is a sudden burst of technologies – drones, AI, BIM. Many are struggling to adapt to all these newfound technologies, worse is some are acquiring some technologies. This is interesting because as a part of her program Anna wants to drive forward the behavior, working methods and organization change brought about by the use of AI rather than the technology in and of itself.

Blue

Moving onwards, the blue section concerns the job and performance evolutions section. As per the interview rationale, the very first question of this section attempts to acquire some raw, almost of quantitative nature, data from this question. From Helena's research perspective, she claims it hard to identify such results and numbers, as accidents often happen in cycles, plus there is commonly instances with false positive and false negative incidents identified by the already established unstructured data. As for Richard, he didn't have any numbers or results off the top if his head but questioned whether these results we sought for were numerical in terms of life or in terms of value which is very interesting, humanistic thought process toward the question.

Extra non-categorizable line of thoughts:

In this part of the analysis, the investigation will be turned toward all, 'improvise' conversations and notions discussed with the interview participants. In a sense this is a rich pool of data as it extracts the deepest knowledge of each participant and enables their gathering to enrich the ensuing discussion. Granted that this part is unfortunately heavily biased toward Richard, however in data terms he possessed the most knowledge and methodologically this was the study's final interview and off script improvisation skills was at its easiest. This being said, Richard began an in-depth conversation about the meaning of AI for safety which was truly enlightening. In simple terms it is that identifying that someone is not wearing the hardhat does not equate solving the problem. 'Anybody who decides to be unsafe will be unsafe' (Appendix E), just because one reminds them to behave safely doesn't mean they are going to start to change their behavior.

IX. DISCUSSION

In this section, the thesis seeks to explore and interpret the bridging of the previous theoretical and empirical chapters. The structure adopted reflects that of the latter two parts of the literature review and the overall study research questions. The first section of this discussion considers Safety in construction more specifically into the safety roles and the associated performance. Following this is an understanding of how construction safety jobs and the implicit collaborative dynamics are affected during a digital transformation. It is given that the extents of impartiality of the interviewees due to their profession is considered as well as the overall generalization of rhetoric from the relatively small population sample for the empirical data.

SAFETY IN CONSTRUCTION

As introduced in accordance with the second part of the literature covering - safety management theories, safety in construction, safety and AI and finally current trends and pilot projects for construction safety – as well as the first sub-research question– into a nuanced interpretation of facts, theories, and line of thoughts from the interview participants.

DIGITAL TRANSFORMATION

Moving forwards, the final part of the literature review covers digital transformations – levels of digital transformation, implications for organizations, sensemaking, task/job reinvention, knowledge sharing. Running parallel to the literature review and the sub research question (b). This latter part of the discussion delves into the inferences for jobs and the correlated collaborative dynamics

1. Jobs

When it comes to roles and career, various academic literature suggests that there would be elimination on certain jobs (Polyanin et al., 2019; Walker and Lloyd-walker, 2020; Kothman and Faber, 2016) yet the interviewees did not regard it as a negative issue. Richard mentions the upskilling of workers not only as a solution but as an imminent procedure to adopt to the more digitalized future of sector. Helena and John had rather actual examples on how new roles are at the moment; an interdisciplinary knowledgeable person who works as an intermediary, connecting the construction safety side to the AI solution providers either in a permanent or temporary role.

2. Collaborative dynamics

Almost all interviewees were involved in collaborative projects; even John working at Smartvid stated that there are companies who are taking part in collaborative innovative projects with the company. Considering the unique data available in a company deemed as knowledgeable; managing, and sharing it plays a vital role in machine learning projects, yet the distinctive perspectives of the interviewees were noticed. While Anna was positive about the increasing zest on running collaborative projects and sharing knowledge according to her experience, Richard doubted the sufficiency of incentive among managers to share their data, not only due to competitiveness but also for the exposure to critics and the fear of judgement.

While one could benefit from others taking the risk, one will not carry that risk to help others. The loose coupling can be flagged here in that the industry operates in a panoply of individual heterogeneous tightly coupled cells as opposed to a whole (Dubois and Gadde, 2002). From this, the discussion confers with eh notion that while this heterogeneity and inter-independency allows for organizations to take risks and innovate on a small scale, it prevents them from sharing the innovation knowledge appropriately.

On a different note, Agarwal, Chandrasekaran and Sridhar (2016, p 23) established that these types of solutions were hard to upscale and it was often recommended to start on larger projects rather than small ones. Along with Richard consultant work and experience in the field this is also his opinion on the matter.

Qualitative results

As the concept of DT and OSH combined is relatively new and not many industrial enterprises fully adopted it in their system [22], it is difficult to find trends showing fatality and accident rates in the workplace after implementing this technology. As a consequence, lack of results for companies willing to improve their OSH management could be a drawback for them, especially when their stakeholders are doubting whether or not to approve the investment.

However, it is possible to predict the profitability on certain technologies mentioned, for example the VR training, by analysing the way users accept and behave using this technology and their final output from it. Results from [38] after analysing the behaviour of 103 university students on VR-based training for DT based crisis management proved that positive attitude towards the system and having a good sense of control over it are great starting points to try the system. In addition, users who find the training user-friendly tend to think favourably of the system as a whole and utilize it more frequently. Hence, simple usability functions should be adopted while conducting considerate ergonomic studies would be wise to increase the benefits of this application.

On another note, having an already elaborated DT is a huge advantage for enterprises and can have a huge impact on safety management procedures after slight modifications in its technical sides to hit promising corners of workplace safety. While for SMEs that might not have acquired these technologies yet, these concepts, including cost-effective ones, emphasize the value they return after investment as to serve as a wake-up call for their stakeholders to start considering this technological transformation.

Several academics conducted evaluations on construction safety at the project or business levels. It was discovered that small construction firms have more accidents than larger ones. This is because small construction companies have less resources, which makes it challenging to manage construction safety adequately. Contrarily, larger enterprises are more organized, have a higher understanding of workplace safety, and provide more construction worker training [9]. Therefore, providing cost-effective solutions would offer SMEs a huge advantage to ameliorate the condition of their safety management systems. It is the role of a workplace manager to stipulate from his company owners and stakeholders the necessity of adopting technologically advanced safety tools that walk hand in hand with the evolution of a high-risk industry.

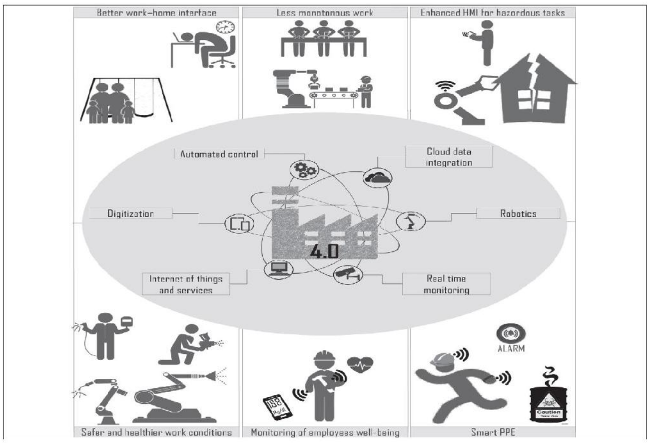

Figure 11. Main opportunities and benefits resulting from the application of Industry 4.0 in workplaces mentioned in [23].

Critical aspects

While there is no doubt that implementing Digital Twin technologies for safety purposes has increasing benefits for workers and for the whole enterprise as well [9], there is still some critical aspects that seem to hinder its implementation in the present time. These aspects are highlighted in the following:

1) The main cause for lack of adoption is that most of the models and methods discussed in section 3 are still laboratory mock-ups in the research stages, hence before being used in serious real-life applications, they are yet required to be studied and modified. For example, the study employed by [26] was said to be “experimental and will need to be scaled up prior to field deployment”.

2) Many of the technologies could require big investments that enterprises might not be willing to take. Although these technologies provide enormous prospects of reducing occupational risks, it is crucial to remember that the employer is unlikely to take the investment in situations where labor is accessibly cheap, competition is strong, and profit margins are small [42].

3) Some DT technologies might not have the required advancement yet for such delicate applications. For example, [7] states that “IoT is not perfectly IIoT (Industrial IoT)”, in other words, the solutions currently available on the market frequently fall short in terms of performance and adaptability because the industrial version of devices demands durable, robust, and dependable solutions that must adhere to industry standards and guidelines.

4) As studies show, utilizing digital technology is linked to certain psychosocial demands (such as increased workload, complexity, and conflicts between work and other life domains) and consequently lead to psychobiological stress reactions [43].

5) Some technologies can be an underlying cause for many workplace risks. VR and AR gadgets in certain situations could be a source of risks because of distraction, information overload, disorientation, motion sickness and eyestrain [42]. While the laboratory scale wearable sensor discussed in [26] is not yet feasible for field deployment as it could hinder workers’ movement and restrict him from fulfilling his tasks in a safe and appropriate manner.

6) Companies using monitoring technologies to ensure workers’ safety would have detailed health status of their employees and might use it for their benefits. Obtaining personal information entails with it a major concern for privacy and more importantly for data misuse, for example managers would deploy promotions or terminate contracts based on information about a worker's health. Such legal and ethical issues demand a considerate public debate among multidisciplinary expert groups [44].

X. CONCLUSION

First and foremost, the conclusion will cover a quick recap of both the literature review and results and findings’ main points. Concerning the former, the first section of the literature review was undertaken with an educational and research driven focus, while the second and third sections do as well, they also highlight various theoretical and academic viewpoints. In the respective order, the key points brought forward are that in general AI is currently revolutionizing all industries including construction. The notion at hand was to establish how permeable and deep could this change go for worksite safety in construction. The scope of the study converged on the more tangible consequences of safety rather than health and focuses on the impact on safety roles and performance as well as implications for jobs and collaborative dynamics between construction organizations on the basis of AI implementation. Understandably, the methodology section covers the data collection process and targeting approach for the duration of the study. The qualitative data acquired from four interview participants divided into four parts in accordance with interview rationale whilst remaining the in the fields of construction/AI/safety. The interview and analysis structure considered first, a deeper look into the in the interviewees’ roles and projects, second, to examine the collaborative relations in each project illustrating different experience in terms of sharing data and collaboration. Lastly, the discussion above enabled an array of strong theoretical viewpoints to be confirmed such as on the one hand the teleological view on the trajectory of change and agency role the leadership concerned plays. On the other hand, the humanistic approach to safety performance was sought out in research and found similar results empirically.

LIMITS OF THE STUDY AND FURTHER RECOMMENDATIONS

The thesis attempted to achieve an understanding and new thoughts on the relatively new subject of machine learning deployment in occupational safety for construction. Naturally, there has been limits and obstacles on the path.

Primarily, what the authors of the thesis consider as a limit is the number of interviewees taking part in the primary data collection. Due to different reasons such as novelty of the topic, the limited time span and influenced circumstances by COVID-19, it remained a challenge to find enthusiastic interviewee with relevant background.

As further recommendations, it is suggested to cast interview over a larger group of actors in the field. This can be improved additionally by conducting a survey as complementary to the interviews in order to grasp a more general insight to the subject.

This study offers insightful information about the combined concept of Digital Twins and Occupational Health and Safety Management with the goal of analyzing current material and methods in this domain. These concepts are becoming more and more significant in daily management activities. Academic studies show that even with the low attentiveness, there are still few DT technologies that are explicitly used for safety management. This paper has proposed promising applications, techniques, and theoretical advancements for the implementation of Digital Twins with the purpose of enhancing the safety level of employees in the workplace.

The models use modernized technologies and serve the workplace in terms of real-time monitoring of employees to ensure work is done in a safe way, risk assessment to predict and eliminate possible harmful scenarios, and deliver workers the most relevant and updated safety trainings using serious Virtual Reality games. The results are limited in numbers since the application of DT for safety purposes is relatively new, however they are promising in case further development and investigation is adopted. On the other side, careful attention needs to be considered to deal with the critical and ethical aspects related to these models. The findings of this study should serve as a wake-up call to various stakeholders and other relevant leaders, who should pursue opportunities that will lead to occupational advancements made possible by DT technologies to eventually promote safety in all its forms. In this context, future works should focus on making certain technologies user friendly to avoid technological pressure on workers who are already doing challenging tasks. In addition, digital twin applications should be further considered and developed to promote safety in process industries in order to ensure that hazardous chemicals and emissions are below critical levels that could cause notorious long-term effects on worker's health.

Finally, a change in constitutional laws and regulations by governments, concerning modern coherent safety tools in advanced and complicated workplaces, would help kick-start and accelerate the adoption of reliable, sustainable, and risk-free technologies.

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