BIM and PLM-Based Management of Occupational Health and Safety: A Comparative Literature Review

Christian Tiaya Tedonchio, christian.tiaya-tedonchio.1@ens.etsmtl.ca
École de technologie supérieure, Montréal, Quebec
Sylvie Nadeau, Sylvie.Nadeau@etsmtl.ca
École de technologie supérieure, Montréal, Quebec

Conrad Boton, Conrad.Boton@etsmtl.ca
École de technologie supérieure, Montréal, Quebec

Louis Rivest, Louis.Rivest@etsmtl.ca
École de technologie supérieure, Montréal, Quebec

Abstract

Workers in the construction industry remain particularly exposed to occupational health and safety (OHS) risks despite recent attempts to use BIM mock-ups to manage OHS. However, workers in the manufacturing industry are less exposed due to the efficient use of PLM mock-ups, among other factors. In this paper, we investigate the works published in the last decade addressing the use of BIM and PLM mock-ups in OHS risk prevention. Then, we compare these two kinds of mock-ups and identify the digitalized information that is integrated into risk management. It emerges that BIM-based OHS risk management mainly integrates information about site configuration and task scheduling, while PLM-based OHS risk management mainly integrates information about task sequences and interactions between humans, products, and tools/equipment. Furthermore, BIM-based approaches are used mainly for managing occupational safety risks, while PLM-based approaches are used mainly for managing human factors/ergonomics (HF/E) risks. To avoid siloed approaches to manage OHS and provide more sustainable and systemic OHS risk mitigation measures, it is more suitable to merge the BIM and PLM approaches. Such an approach would be particularly suitable for integrated risk management of industrial buildings which are at the crossroads of BIM and PLM studies.

Keywords: BIM, PLM, digital mock-up, occupational safety, human factors, ergonomics, risk, prevention, information, interaction, integrated risk management, industrial building.

1. Introduction

Digital transformation makes it possible for various industries to improve their performance and efficiency (Junior et al., 2016; Nadeau and Landau, 2018). In the construction industry, the advent of BIM has made it possible to improve stakeholder performance on projects and thereby reduce construction costs and delays and improve the quality of built facilities (Fytrou-Moschopoulou, 2016). However, despite these positive impacts of BIM mock-ups, the construction industry remains far from being risk-free for site workers. In Quebec, statistics from the Standards, Equity, and Occupational Health and Safety Commission (CNESST) for the year 2019 rank the construction industry first among hazardous industries with 63 deaths, or about three times the number of deaths observed in the processing industry, which ranks second (CNESST, 2020).

This unsafe characteristic of the construction industry is due in part to the great variety of occupational health and safety (OHS) risks that workers are exposed to. In light of the great variety of risks, we are focusing on three main risk categories in this study: industrial hygiene risks, occupational safety risks, and human factors/ergonomics (HF/E) risks. Industrial hygiene risks relate to physical, biological, and chemical risks associated with the working environment, like the spread of dust or contaminants in the air (IST, 2007). The occupational safety risks category focuses on professional injury risks, known as acute risks, such as falls, and mechanical risks, such as collisions with construction machinery (IST, 2007). HF/E risks are those that arise from heavy physical and mental workloads, like from uncomfortable and unsafe working postures imposed on workers. The management of HF/E risks must integrate a wide range of human parameters in the process analysis. Some examples of these parameters include the needs, skills, capacities, and resilience of workers (Peruzzini et al., 2017a). In the manufacturing industry, those parameters can be integrated in workplace HF/E assessments by introducing a virtual mannequin or digital human modeling (DHM) in virtual scenes (Joung et al., 2015).

The reasons generally given to explain the lack of performance of the construction industry, compared to other manufacturing industries such as aeronautics or the automobile, are related to the structural differences existing between them. Indeed, fundamental differences exist between construction processes and operations including the fact that in manufacturing, operations take place in fixed, stable and controlled environments. In construction, the products are static, with repetitive operations in environments exposed to hazards and potentially different for each operation. Thus, overhead for digital mock-up (DMU) is more important and the modeling of construction processes and operations is more costly in terms of time and resources. However, since various provincial and national occupational health and safety statutes, like Quebec's *Act respecting occupational health and safety,* recommend risk prevention at the source, there is much literature proposing the use of digital mock-ups for early hazard identification in the construction industry (Fargnoli and Lombardi, 2020; Martínez-Aires et al., 2018) and other sectors including the manufacturing industry. In the aeronautical and automotive industries, for example, PLM mock-ups are used very early in the design phase for HF/E design and analysis of workplaces and processes to improve worker's health and safety (Joung et al., 2015).

Despite the similarities between BIM and PLM approaches, there is virtually no research work dedicated to the comparison between the use of BIM-type and PLM-type mock-ups for occupational health and safety management. However, such a comparison is important to improve BIM practices through a good understanding of good PLM practices, and vice versa. Hence, the question being examined in this paper is: what are the similarities and differences in how BIM and PLM mock-ups are used as a means of preventing OHS risks? Therefore, the expected contribution is to provide a comparative study of the use of BIM and PLM mock-ups for OHS risk prevention. We consider that DMUs basically contain geometric information describing the work environment. Since the literature suggests that geometry alone is not sufficient to conduct specialized analysis (Ferrise et al., 2013), the comparison of how DMUs are used in the construction and manufacturing industries will focus on the "preparation" of the DMUs for risk analysis. This preparation may include non-geometric information that is integrated in hazard identification. Therefore, this paper focuses on identifying various DMU preparation methods found in the literature, with a focus on the OHS risks generated at the operation stage.

The rest of this paper is structured as follows. Section 2 presents the related works. Section 3 presents the methodology adopted. Section 4 presents a state of the art of how BIM mock-ups are used for risk prevention. Section 5 presents a state of the art of how PLM mock-ups are used for risk prevention. In Section 6, we highlight the similarities and differences in how BIM and PLM mock-ups are used for hazard identification and the scientific opportunities for the integrated operational risk management of industrial buildings. Section 7 concludes the paper.

2. Related Studies

With the advent of BIM, many studies have focused on the use of this technology to improve the health and safety of workers in the construction industry. Martínez-Aires et al. (2018) conducted a systematic literature review on works published between 1981 and 2016 on the topic. The aim of that review was to explore how the management-driven approach to OHS is changing with the use of BIM. They find that BIM is making it possible to identify hazards early, before the start of any on-site activities, through the visual representation of relevant site conditions, the 4D schedule and the sequencing of site logistics. Fargnoli and Lombardi (2020) conducted a systematic literature review of works published between 2010 and 2019 with the objective of highlighting the roles played by BIM-based tools for OHS purposes. It emerges from their work that BIM-based tools that are used for OHS purposes target eight main areas: (1) information provision through knowledge-based systems, (2) safety rule codification for automatic rule-checking, (3) the release / communication of information, (4) overlap and clash resolution, (5) real-time warning and feedback, (6) worker training, (7) stakeholders' perception of the advantages of using BIM for construction safety, and (8) workers' behavior. However, the shortcoming of those studies, as noted by Forsythe (2014), is that they are mainly focused on the design phase, without anticipating the unexpected dynamics of construction and related human behavior. Forsythe (2014) therefore reviews the literature on proactive technologies (e.g., movement sensors housed in a safety helmet) that are combined with BIM mock-ups and used during the construction phase. He also identifies scientific opportunities for improving the HF/E of the proactive technologies used to promote their acceptance by workers in daily work situations.

Since provincial OHS statutes recommend eliminating risks at the source, we wonder if it is possible to better integrate the dynamic nature of construction and operational activities and interactions between humans, tasks, and tools/equipment earlier in the design through better preparation of BIM mock-ups?

Some recent research recommends relying on the best practices observed in PLM applications to break through the barrier that still stands in the way of better deployment of BIM (Aram and Eastman, 2013; Boton et al., 2016). For example, Jupp (2013) established that PLM's core functions can effectively be used to address the impediments encountered when trying to fully implement BIM in construction projects. Besides that, some authors have noted that some differences can be observed in BIM and PLM model use for OHS purposes. For example, when it comes to using BIM and PLM mock-ups coupled with VR technologies, Getuli et al. (2020) noted that in the construction industry, current research focuses mainly on visualization and immersive capabilities, while in manufacturing industry, these technologies are used to effectively simulate assembly tasks in an HF/E approach to workplace design.

Therefore, to take advantage of the manufacturing industry's experience with using PLM mock-ups for OSH risk prevention, we investigate in this paper the use of both DMUs (BIM and PLM) as a means of preventing OHS risks.

3. Research methodology

We based our literature review on works published between 2010 and 2020. The databases we consulted are: Engineering Village, Scopus, and ScienceDirect. We used the following keywords in English: BIM, PLM, digital mock-up, design, plant, building, operation, construction, occupational health, safety, prevention, hazard, recognition, identification, engineering process, prevention through design, and automation. The list of references was then supplemented by the snowball effect and refined based on summary analysis. When analyzing the summary, we kept in mind two main aspects of our topic: the digital mock-up aspect, and the hazard identification / risk prevention aspect. All articles that dealt with one aspect without addressing the other were automatically rejected. Those that specifically addressed the risks associated with the stability of temporary structures were rejected, as were publications that dealt with risks related to collaboration between humans and robots in the manufacturing industry. We kept only articles whose objectives included OHS hazards or risks and at least one of the two kinds of mock-ups that we are comparing. This analysis enabled us to classify the references according to the prevention objectives that they targeted (the type of hazard to be identified) and the phases of the project life cycle during which they are used. Finally, an in-depth analysis of the references selected made it possible to identify the non-geometric information integrated in hazard identification. That is what is shown in the "Type of additional information" column in Table 1. The comparative analysis was supported by the following elements characterizing work situations (Division Santé et sécurité au travail, 2010): task sequence as prescribed, task schedule, equipment/resources, workplace, and HF/E. Therefore, we discuss and highlight the similarities and differences in how BIM and PLM mock-ups are used for OHS risk prevention.

Table 1. Classification of literature integrating BIM and PLM mock-ups as a mean of preventing OHS risks

Approach	Project phase	Source	Type of additional information	Kind of risks identified
		BIM Mock-Ups		
3D BIM	Design	Kasirossafar et al., 2012	None	Risks related to initial site configuration (**Occupational Safety**)
4D BIM	Design	Shang and Shen, 2016; Tran and Pham, 2020; Trani et al., 2015; Guevremont and Hammad, 2018; Jin et al., 2019	Construction task schedule	Risks related to the management of construction machinery and vehicles on site (**Occupational Safety**)
3D + Color Code	Design	Cortés-Pérez et al., 2020	OHS regulations	Risks related to the spatial location of 3D BIM objects (**Occupational Safety**)
3D/4D BIM + Specialized Databases	Design	Mihić et al., 2018; Hossain et al., 2018	Construction task schedule + Task sequence + Resources (material and equipment) + Human	Various types of risk (physical, mechanical, chemical, biological, etc.) related to the construction of 3D BIM objects like struck by objects or to the properties of materials to be handled (**Industrial Hygiene, Occupational Safety**)
3D BIM + Knowledge Modeling	Design	Ding et al., 2016; Zhang et al., 2014	Construction task sequence + Task schedule + OHS regulations	Risks related to each task sequence and to different risk factors (**Occupational Safety**)
4D BIM + IoT + Cyber-Physical Systems	Construction	Jiang et al., 2020	Construction task schedule + Worker and equipment movement	The position of workers in relation to hazardous areas and equipment on site (**Occupational Safety**)
4D BIM + IoT + Video Game Technology	Construction	Forsythe, 2014	Construction task schedule + Worker and equipment movement	The position of workers in relation to hazardous areas and equipment on-site (**Occupational Safety**)
3D BIM + Data Transfer Mechanism	Operation	Wetzel and Thabet, 2018	FM hazards related to the location of 3D BIM objects and materials used + Safety procedures	Risks related to falling, being in a harmful area, and being struck-by objects (**Occupational Safety**)
3D BIM + Avatars	Operation	Zhao et al., 2019	Operational task sequence + Time	None
4D BIM + DHM	Design Construction	Golabchi et al., 2018	Construction task schedule + Task sequence + Human–task interaction	Risks related to physical ergonomics (**Ergonomic**)
		PLM Mock-Ups		
PLM + DHM	Design Production	Caputo et al., 2019; Illmann et al., 2013; Sanjog et al., 2019	Equipment + Task sequence + Human–task interaction	Risks related to physical ergonomics (**Ergonomic**)
PLM + DHM + Real-Time Motion Capture	Production	Joung et al., 2015	Equipment + Task sequence + Human–task interaction	Risks related to physical ergonomics (**Ergonomic**)
PLM + DHM + VR/AR	Design	Peruzzini et al., 2017b, 2017a	Equipment + Task sequence + Human–task interaction	Risks related to physical ergonomics (**Ergonomic**)
PLM + VR	Design	Ferrise et al., 2013; Grajewski et al., 2013	Equipment + Task sequence + Human–task interaction	Risks related to physical ergonomics (**Ergonomic**)
PLM + HAZOP + Knowledge-Based System	Design	Bragatto et al., 2007	Equipment operation	Risks of equipment malfunction (**Occupational Safety**)
PLM + HAZOP + Cyber-Physical Systems	Production	Lee et al., 2019	Equipment operation	Risks of equipment malfunction (**Occupational Safety**)
PLM + IoT	Production	Gröger et al., 2016; Ziegler et al., 2015	Equipment + Task sequence (operating data for maintenance)	Risks of equipment malfunction (**Occupational Safety**)

4. State of the art of BIM-based approaches for preventing OHS risks

Table 1 highlights two major trends in the BIM universe: approaches that rely essentially on information provided by 3D and 4D models (Guevremont and Hammad, 2018; Jin et al., 2019; Kasirossafar et al., 2012; Shang and Shen, 2016; Tran and Pham, 2020; Trani et al., 2015), and approaches that find it necessary to add to 3D and 4D models other detailed information that should be relevant for hazard analysis (Forsythe, 2014; Golabchi et al., 2018; Hossain et al., 2018; Jiang et al., 2020; Mihić et al., 2018; Wetzel and Thabet, 2018; Zhang et al., 2014; Zhao et al., 2019).

4.1. Approaches that use information contained in 3D and 4D BIM mock-ups

The first trend in BIM mock-up use for OHS purposes is using the visual information provided by 3D mock-ups. This visual information is essentially geometric shapes, spatial arrangements and the distribution of equipment and materials on site that can be used to virtually visit the site and optimize the management of equipment and dangerous areas (Kasirossafar et al., 2012). However, this virtual site inspection remains frozen in time on the initial site configuration. The task schedule information makes it possible to consider the changing nature of the construction site as work progresses.

This task schedule information is provided by 4D BIM models and can be used in different ways. Shang and Shen (2016) proposed a methodology to valorize task schedule information by forecasting the movement of construction machinery and vehicles on site and then identifying various risks of collision. Tran and Pham (2020) suggest assigning a workspace to each 3D BIM object, linking those workspaces to the 4D schedule, identifying potential conflicts between those workspaces by visualization and adjusting the work schedule accordingly. Trani et al. (2015) recommend taking advantage of the 4D visualization method and the information provided by 4D BIM models about the task schedule and allocated human and material resources to define the different periods during which site configuration does not change. For each of these periods, it would then be easy to safely design the site configuration, organize the sequence of work and assign workspaces to workers for the construction phase. Guevremont and Hammad (2018), for their part, proposed a methodology to analyze critical activities based on their period and zone by linking 4D simulations and safety planning. Thus, they suggest matching to each critical hazard a generic representation that would be joined to a corresponding hazardous area. It would then be possible to visualize the riskiest areas during a 4D simulation and then evaluate the dangerousness of a 4D scenario based on a statistical analysis of historical safety issues. This makes it possible to apply mitigation measures by altering either the task schedule or the 3D BIM model by adding protective measures.

This being said, it should be noted that the 3D BIM and 4D BIM simulation approaches mainly valorize geometric information and task schedule information to identify occupational safety risks linked to the spatial and temporal disposition of resources on the site.

4.2. Approaches that add information to BIM mock-ups for risk analysis

The additional information that recent studies have tried to add to BIM models essentially pertains to standard operating procedures or task sequences, tools to be handled by workers, and corresponding hazards. For example, Mihić et al. (2018) aim to contribute to the automatic detection of hazards based on BIM mock-ups and developed two interconnected databases: one containing construction sector hazard information and the other containing the task sequence of construction activities. Zhang et al. (2015) developed a construction safety ontology in which they record and organize safety management information. This information pertains mainly to the construction task sequence, corresponding hazards, mitigation measures, and the safety specifications that govern them. Ding et al. (2016) propose to manage construction risk knowledge by representing it in a structured form in an ontology that would interact with the BIM models by means of a reasoning engine. This would make it possible to quasi-automatically identify the construction hazards and corresponding risk factors that are linked to the construction of each 3D BIM object. And Hossain et al. (2018), among others, developed a rule-based design for safety knowledge library to capture safety knowledge and support the designer during project design. The proposed framework integrates information about the construction activities of each 3D BIM object and the related risks due to a physical parameter that constrains the BIM object's design (e.g., a beam that could break during lifting due to its length).

During the construction phase, BIM mock-ups can be coupled with proactive technologies such as cyber-physical systems (Jiang et al., 2020) or with video game technology to fuse the 3D BIM model with real-time tracking technology (connected objects that are integrated in workers' PPE and on-site equipment) (Forsythe, 2014). In this example, the additional information that is recorded during the construction phase for risk analysis is workers' position relative to hazardous areas and on-site equipment.

When it comes to the operation phase, the risks faced by maintenance workers is not well addressed in the BIM literature (Martínez-Aires et al., 2018). However, one of the trends that aims to consider risks in the operation phase focuses on the preparation of the BIM mock-up obtained at the end of the construction phase by integrating information that will facilitate its use during the operation phase (Health and Safety Executive, 2018; Wetzel and Thabet, 2018). This preparation of the mock-up involves integrating in the mock-up information about the safety maintenance procedure and potential hazards related to 3D BIM objects. In addition to those works, we note the one by Zhao et al. (2019) that, without aiming to analyze the risks associated with a building's operation phase, lays the foundation for simulating human activities in interior spaces during the design phase. They propose to use avatars from video game technology to simulate daily activities in the BIM mock-up of an indoor environment. Thus, they suggest using a BIM editor to assign 3D BIM objects interaction property information (e.g., "sittable" for a chair or a bed) and a task planner to assign virtual agents the task sequence reflecting their daily objectives and allow them to interact with 3D BIM objects.

5. State of the art of PLM-based approaches for preventing OHS risks

The trends in PLM mock-up use for OHS risk prevention have two main interests: simulating interactions between humans and their workstations (Caputo et al., 2019; Ferrise et al., 2013; Grajewski et al., 2013; Joung et al., 2015; Peruzzini et al., 2017b, 2017a; Sanjog et al., 2019), and using plant mock-ups to manage machine safety risks (Bragatto et al., 2007; Gröger et al., 2016; Lee et al., 2019; Ziegler et al., 2015).

5.1. Approaches that use PLM mock-ups and virtual mannequins to simulate interactions between humans and their workstations

The manufacturing industry has made great strides in using PLM mock-ups for safe workplace design. The identification of hazards is perceived as anticipation of hazardous scenarios (Cameron et al., 2017), with the objective being to virtually simulate the behavior of all components of the production system, ranging from machines to humans (Joung et al., 2015). Caputo et al. (2019) therefore propose a methodology to introduce DHM in a virtual scenario and identify HF/E risks using the EAWSdigital (European Assessment Work Sheet) by methods-time measurement. This approach incorporates hazard identification information on so-called P3RH: products, plants, processes, resources, and humans (Joung et al., 2015). It then makes it possible to identify HF/E risks linked to work postures, the forces to be exerted, the manual handling of materials and the repetitive movement of upper limbs. However, it has two drawbacks: the relative immobility of the mannequin (Illmann et al., 2013; Joung et al., 2015) and the simplification of human behavior (Ferrise et al., 2013).

To solve the deficiencies associated with the immobility of the virtual mannequin, Joung et al. (2015) propose a methodology to add information about the worker to the above P3RH information by using motion sensors to capture the movement of the real worker in the factory and attach it to the virtual mannequin. However, Joung et al. (2015) used this HF/E risk analysis for a plant in the production phase. To prevent HF/E risks during the design phase, Peruzzini et al. (2017b) propose a methodology that couples PLM mock-ups of products and virtual humans to a real human by means of virtual reality (VR) , and Peruzzini et al. (2017a) propose a methodology that couples PLM mock-ups of products and virtual humans to a real human by means of mixed reality (VR + augmented reality). Once implemented, "the methodology makes it possible to realize five mains analysis: postures, occlusion (visibility and accessibility), mental load, interactions and emotions" (Peruzzini et al.; 2017b). However, a shortcoming due to the simplification of interactions between the human and products remains.

According to Ferrise et al. (2013), resolving this shortcoming linked to the approximation of human–product interactions using a virtual human constitutes the basis of the latest technological development in PLM mock-ups. They therefore introduce the concept of interactive virtual prototypes, which refers to the preparation of mock-ups by integrating the information needed to model human–tool gestural interactions (Nadeau and Landau, 2018) and information about the dynamic behavior of objects (Xiong et al., 2016) when they interact with humans. This mock-up preparation makes it possible to transcribe the product model into sensations that are accessible to real humans via the multimodal and multisensory interfaces offered by VR and AR technologies (for example, a MOOG HapticMaster 3DOF haptic device makes it possible to provide force-feedback to the human who is interacting with the virtual product). Grajewski et al. (2013) in turn introduce the notion of "virtual aided design" for HF/E workplace design. This notion also refers to the ability of virtual prototypes of products and workplaces to be tested by real humans by means of VR and haptic technologies.

Thus, PLM-based approaches harness detailed product, process, resource, and human information that is necessary to simulate task sequencing on an individual scale. This makes it possible to identify HF/E risks. These approaches are mainly used during the design phase.

5.2. Approaches that use PLM mock-ups to manage machine safety risks

In addition to the approaches that tend to simulate work situations during the design phase by integrating humans or DHMs in virtual scenes, other approaches that date back to the 1990s are based on process simulation without including humans (Cameron et al., 2017). These are mostly used to automate the main traditional methods of hazard identification: HAZOP and FMEAC, which are generally built on knowledge-based systems in which we can record relevant information about the operating modes of equipment and, in turn, their malfunction modes or deviations. By considering their relative arrangement in the plant and their functional connections, it is then possible to identify hazardous scenarios specific to a particular plant and instrumentation diagram using a reasoning engine and thus support the OHS practitioner investigating the system behavior (Lee et al., 2019) and then complete hazard identification (Bragatto et al., 2007).

During the production phase, tools are put in place to monitor workers and the operating mode of machines in real time. With the introduction of Industry 4.0, there is a wide variety of these types of OHS risk prevention tools. Work equipment uses cyber-physical systems to self-monitor their operational safety (Gröger et al., 2016). Sensors are used to alert workers in real time of the possible presence of a risk (Nadeau and Landau, 2018). Other tools such as smartwatches are also used to collect data about the operational safety of plant equipment and provide work procedures to assist workers in performing theirs tasks (Gröger et al., 2016; Ziegler et al., 2015). This makes it possible, to mitigate risks linked to machine safety during the production phase.

6. Discussion

Considering the previous analysis, it is apparent that researchers tried to integrate in the hazard identification process based on the two types of DMUs (BIM and PLM), P3RH information and do so at different scales. That is why they contribute to identifying different kind of risks: mainly occupational safety risks for BIM-based approaches and mainly HF/E risks for PLM-based approaches. More specifically:

(1) While BIM mock-ups using 4D simulation have attempted to reproduce hazardous scenarios at the construction site scale (thus, at the entire workplace scale), PLM mock-ups reproduce hazardous scenarios on a smaller scale, at the scale of an individual workstation. This is apparent in the fact that the 4D scenarios as presented in section 4.1 aim primarily to identify the conflicts that could arise between the spaces that are allocated to different resources as the project progresses. Therefore, the task schedule is the main non-geometric information that is added to the geometric information. While the PLM-based approaches rely mainly on

information about task sequences and HF/E (people's physical and mental capacities), which makes it possible to define the interactions to be simulated between humans, tasks, and resources.

(2) The construction industry also needs to be able to replicate smaller-scale hazardous scenarios. This is probably why recent studies have tried to record in databases detailed information about task sequences and related hazards.

(3) In the construction industry, the trend in research is to try to support designers in their decision-making by attempting to provide them with information about mitigation measures and OHS specifications with the objective of automating the hazard identification process and design verification.

It appears that for the operation stage of an industrial building, we can rely on the BIM-based management approaches of OHS to provide mitigation measures to occupational safety risks to which workers will be exposed due to the complexity of their working environment and we can rely on the PLM-based management approaches to provide mitigation measures to occupational safety risks due to the interaction between workers and industrial equipment and to HF/E risks to which workers will be exposed due to the requirements of the prescribed task to perform. Thus, we can join Fortineau et al. (2019) in their thought that "despite the fact that the businesses of AEC (targeted by BIM) and classical industrial sectors (aerospace, automotive, steel industry) are slightly different, there are similarities and connection points that will hopefully make BIM and PLM systems more cooperative in the future".

7. Conclusion

Our objective was to identify the similarities and differences in how BIM and PLM mock-ups are used for OHS risk prevention. We conducted a literature review of works published between 2010 and 2020 on Engineering Village, Scopus and ScienceDirect pertaining to the use of BIM or PLM mock-ups for OHS risk prevention. The analysis we carried out afterwards focused mainly on digitalized information used to replicate work situations and then identify dangerous scenarios. The characteristic elements guiding our analysis were task sequence, task schedule, equipment/resources, workplace, and HF/E. We also identify the kind of risks that each approach makes it possible to identify. On one hand, BIM-based approaches mainly integrate task schedule information and combine it with geometric information to identify occupational safety risks by replicating hazardous scenarios at the construction site scale. On the other hand, PLM-based approaches mainly integrate task sequence and human information to simulate interactions between humans, tasks, and resources at the individual workstation scale. Then, it presents a scientific opportunity to provide a mixture of the two approaches to better integrate the dynamic nature of construction and operational activities and interaction between human and their tasks in hazard identification process, particularly for the operation of industrial buildings. Thus, we think that the subsequent risk mitigation measures may be more systemic and sustainable.

Acknowledgements

The authors would like to thank the industrial partner, NSERC and ETS for their support of this research project.

References

Aram, S., Eastman, C., 2013. Integration of PLM Solutions and BIM Systems for the AEC Industry. Presented at the 30th International Symposium on Automation and Robotics in Construction and Mining; Held in conjunction with the 23rd World Mining Congress, Montreal, Canada. https://doi.org/10.22260/ISARC2013/0115

Boton, C., Rivest, L., Forgues, D., Jupp, J., 2016. Comparing PLM and BIM from the Product Structure Standpoint, in: Harik, R., Rivest, L., Bernard, A., Eynard, B., Bouras, A. (Eds.), Product Lifecycle Management for Digital Transformation of Industries. Springer International Publishing, Cham, pp. 443–453.

Bragatto, P., Monti, M., Giannini, F., Ansaldi, S., 2007. Exploiting process plant digital representation for risk analysis. Journal of Loss Prevention in the Process Industries 20, 69–78. https://doi.org/10.1016/j.jlp.2006.10.005

Cameron, I., Mannan, S., Németh, E., Park, S., Pasman, H., Rogers, W., Seligmann, B., 2017. Process hazard analysis, hazard identification and scenario definition: Are the conventional tools sufficient, or should and can we do much better? Process Safety and Environmental Protection 110, 53–70. https://doi.org/10.1016/j.psep.2017.01.025

Caputo, F., Greco, A., Fera, M., Caiazzo, G., Spada, S., 2019. Simulation Techniques for Ergonomic Performance Evaluation of Manual Workplaces During Preliminary Design Phase, in: Bagnara, S., Tartaglia, R., Albolino, S., Alexander, T., Fujita, Y. (Eds.), Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). Springer International Publishing, Cham, pp. 170–180.

CNESST, 2020. Statistiques 2019.

Cortés-Pérez, J.P., Cortés-Pérez, A., Prieto-Muriel, P., 2020. BIM-integrated management of occupational hazards in building construction and maintenance. Automation in Construction 113, 103115. https://doi.org/10.1016/j.autcon.2020.103115

Ding, L.Y., Zhong, B.T., Wu, S., Luo, H.B., 2016. Construction risk knowledge management in BIM using ontology and semantic web technology. Safety Science 87, 202–213. https://doi.org/10.1016/j.ssci.2016.04.008

Division Santé et sécurité au travail, 2010. Identification des dangers et analyse de risques : Guide de référence.

Fargnoli, M., Lombardi, M., 2020. Building Information Modelling (BIM) to Enhance Occupational Safety in Construction Activities: Research Trends Emerging from One Decade of Studies. Buildings 10, 98. https://doi.org/10.3390/buildings10060098

Ferrise, F., Bordegoni, M., Cugini, U., 2013. Interactive Virtual Prototypes for Testing the Interaction with new Products. Computer-Aided Design and Applications 10, 515–525. https://doi.org/10.3722/cadaps.2013.515-525

Forsythe, P., 2014. Proactive construction safety systems and the human factor. Proceedings of the Institution of Civil Engineers - Management, Procurement and Law 167, 242–252. https://doi.org/10.1680/mpal.13.00055

Fortineau, V., Paviot, T., Lamouri, S., 2019. Automated business rules and requirements to enrich product-centric information. Computers in Industry 104, 22–33. https://doi.org/10.1016/j.compind.2018.10.001

Fytrou-Moschopoulou, A., 2016. Shaping the Future of Construction: A Breakthrough in Mindset and Technology [WWW Document]. Build Up. URL https://www.buildup.eu/en/practices/publications/shaping-future-construction-breakthrough-mindset-and-technology-0 (accessed 4.15.21).

Getuli, V., Capone, P., Bruttini, A., Isaac, S., 2020. BIM-based immersive Virtual Reality for construction workspace planning: A safety-oriented approach. Automation in Construction 114, 103160. https://doi.org/10.1016/j.autcon.2020.103160

Golabchi, A., Han, S., AbouRizk, S., 2018. A simulation and visualization-based framework of labor efficiency and safety analysis for prevention through design and planning. Automation in Construction 96, 310–323. https://doi.org/10.1016/j.autcon.2018.10.001

Grajewski, D., Górski, F., Zawadzki, P., Hamrol, A., 2013. Application of Virtual Reality Techniques in Design of Ergonomic Manufacturing Workplaces. Procedia Computer Science 25, 289–301. https://doi.org/10.1016/j.procs.2013.11.035

Gröger, C., Kassner, L., Hoos, E., Königsberger, J., Kiefer, C., Silcher, S., Mitschang, B., 2016. The Data-driven Factory - Leveraging Big Industrial Data for Agile, Learning and Human-centric Manufacturing:, in: Proceedings of the 18th International Conference on Enterprise Information Systems. Presented at the 18th International Conference on Enterprise Information Systems, SCITEPRESS - Science and and Technology Publications, Rome, Italy, pp. 40–52. https://doi.org/10.5220/0005831500400052

Guevremont, M., Hammad, A., 2018. 4D Simulation Considering Adjusted Schedules for Safety Planning in Hydroelectric Projects, in: EG-ICE.

Health and Safety Executive, 2018. Improving Health and Safety Outcomes in Construction: Making the Case for Building Information Modelling (BIM) 43.

Hossain, Md.A., Abbott, E.L.S., Chua, D.K.H., Nguyen, T.Q., Goh, Y.M., 2018. Design-for-Safety knowledge library for BIM-integrated safety risk reviews. Automation in Construction 94, 290–302. https://doi.org/10.1016/j.autcon.2018.07.010

Illmann, B., Fritzsche, L., Leidholdt, W., Bauer, S., Dietrich, M., 2013. Application and Future Developments of EMA in Digital Production Planning and Ergonomics, in: Duffy, V.G. (Ed.), Digital Human Modeling and Applications in Health, Safety, Ergonomics, and Risk Management. Human Body Modeling and Ergonomics. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 66–75.

IST, 2007. Introduction à l'hygiène du travail: un support de formation, Série protection de la santé des travailleurs. Institut universitaire romand de santé au Travail.

Jiang, W., Ding, L., Zhou, C., 2020. Cyber physical system for safety management in smart construction site. ECAM ahead-of-print. https://doi.org/10.1108/ECAM-10-2019-0578

Jin, Z., Gambatese, J., Liu, D., Dharmapalan, V., 2019. Using 4D BIM to assess construction risks during the design phase. ECAM 26, 2637–2654. https://doi.org/10.1108/ECAM-09-2018-0379

Joung, Y.-K., Li, Q., Noh, S.D., 2015. XML-based neutral schema for automated ergonomic analysis with digital human simulation and inline motion capture. International Journal of Computer Integrated Manufacturing 1–17. https://doi.org/10.1080/0951192X.2014.972459

Junior, J.C. da S.F., MaCada, A.C., Brinkhues, R., Montesdioca, G.P.Z., 2016. Digital Capabilities as Driver to Digital Business Performance, in: AMCIS.

Jupp, J.R., 2013. Incomplete BIM Implementation: Exploring Challenges and the Role of Product Lifecycle Management Functions, in: Bernard, A., Rivest, L., Dutta, D. (Eds.), Product Lifecycle Management for Society. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 630–640.

Kasirossafar, M., Ardeshir, A., Shahandashti, R.L., 2012. Developing the Sustainable Design with PtD Using 3D/4D BIM Tools.

Lee, J., Cameron, I., Hassall, M., 2019. Improving process safety: What roles for Digitalization and Industry 4.0? Process Safety and Environmental Protection 132, 325–339. https://doi.org/10.1016/j.psep.2019.10.021

Martínez-Aires, M.D., López-Alonso, M., Martínez-Rojas, M., 2018. Building information modeling and safety management: A systematic review. Safety Science 101, 11–18. https://doi.org/10.1016/j.ssci.2017.08.015

Mihić, M., CERIĆ, A., ZAVRŠKI, I., 2018. Developing Construction Hazard Database for Automated Hazard Identification Process. Teh. vjesn. 25. https://doi.org/10.17559/TV-20180417105624

Nadeau, S., Landau, K., 2018. Nadeau S and Landau K. Utility, Advantages and Challenges of Digital Technologies in the Manufacturing Sector. Ergonomics Int J 2018, 2(6): 000188. 15.

Peruzzini, M., Carassai, S., Pellicciari, M., 2017a. The Benefits of Human-centred Design in Industrial Practices: Re-design of Workstations in Pipe Industry. Procedia Manufacturing 11, 1247–1254. https://doi.org/10.1016/j.promfg.2017.07.251

Peruzzini, M., Carassai, S., Pellicciari, M., Andrisano, A.O., 2017b. Human-centred design of ergonomic workstations on interactive digital mock-ups, in: Eynard, B., Nigrelli, V., Oliveri, S.M., Peris-Fajarnes, G., Rizzuti, S. (Eds.), Advances on Mechanics, Design Engineering and Manufacturing : Proceedings of the International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2016), 14-16 September, 2016, Catania, Italy. Springer International Publishing, Cham, pp. 1187–1195. https://doi.org/10.1007/978-3-319-45781-9_119

Sanjog, J., Patel, T., Karmakar, S., 2019. Occupational ergonomics research and applied contextual design implementation for an industrial shop-floor workstation. International Journal of Industrial Ergonomics 72, 188–198. https://doi.org/10.1016/j.ergon.2019.05.009

Shang, Z., Shen, Z., 2016. A Framework for a Site Safety Assessment Model Using Statistical 4D BIM-Based Spatial-Temporal Collision Detection, in: Construction Research Congress 2016. Presented at the Construction Research Congress 2016, American Society of Civil Engineers, San Juan, Puerto Rico, pp. 2187–2196. https://doi.org/10.1061/9780784479827.218

Tran, N.N.T., Pham, H.L., 2020. 4D BIM Workspace Conflict Detection for Occupational Management A Case Study for Basement Construction Using Bottom Up Method, in: Proceedings of the 2020 The 4th International Conference on E-Education, E-Business and E-Technology. Presented at the ICEBT'20: 2020 The 4th International Conference on E-Education, E-Business and E-Technology, ACM, Shanghai China, pp. 72–77. https://doi.org/10.1145/3404649.3406879

Trani, M.L., Cassano, M., Todaro, D., Bossi, B., 2015. BIM Level of Detail for Construction Site Design. Procedia Engineering 123, 581–589. https://doi.org/10.1016/j.proeng.2015.10.111

Wetzel, E.M., Thabet, W.Y., 2018. A case study towards transferring relevant safety information for facilities maintenance using BIM. Journal of Information Technology in Construction (ITcon) 23, 53–74.

Xiong, W., Wang, Q.-H., Huang, Z.-D., Xu, Z.-J., 2016. A framework for interactive assembly task simulationin virtual environment. Int J Adv Manuf Technol 85, 955–969. https://doi.org/10.1007/s00170-015-7976-3

Zhang, S., Boukamp, F., Teizer, J., 2015. Ontology-based semantic modeling of construction safety knowledge: Towards automated safety planning for job hazard analysis (JHA). Automation in Construction 52, 29–41. https://doi.org/10.1016/j.autcon.2015.02.005

Zhang, S., Sulankivi, K., Romo, I., Eastman, C., 2014. BIM-based fall hazard identification and prevention in construction safety planning | Elsevier Enhanced Reader [WWW Document]. https://doi.org/10.1016/j.ssci.2014.08.001

Zhao, Y., Fatemi Pour, F., Golestan, S., Stroulia, E., 2019. BIM Sim/3D: Multi-Agent Human Activity Simulation in Indoor Spaces, in: 2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS). Presented at the 2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS), IEEE, Montreal, QC, Canada, pp. 18–24. https://doi.org/10.1109/SEsCPS.2019.00011

Ziegler, J., Heinze, S., Urbas, L., 2015. The potential of smartwatches to support mobile industrial maintenance tasks. 2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA) 1–7.