

Overall Introduction to the Framework of BIM-based Digital Twinning in Decision-making in Safety Management in Building Construction Industry

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Abstract

There is a growing impact of digitalization on the management processes in the construction industry. This trend enhances changes in decision-making related to the Occupational Health and Safety. This paper aims to study the Building Information Modelling (BIM) and digital twin technology integration within the decision-making processes related to safety management in building construction industry. Considering the complexity of the occupational health and safety management, the decision-making processes and operational performance in this field requires special emphasis on communication, data gathering and feedback organization-wide.

As technologies advanced and flexible enough, the BIM-based digital twinning provides an opportunity to give decision-making support in the scope of complex situations and comprehensive data management of construction projects. Through the real-time interfaces and the users' information sharing BIM-based digital twinning is a big step in the direction of safety management based on predictive analysis, all users/workers inclusion and smart assets optimization and assessment of the decision-making processes at all operational levels. As the application of BIM methods is widely spread along the whole cycle of building construction from the project definition till the post-execution inspection, the correct and predictive data collection from BIM and its' 3D visualization through digital twins stand out as a significative progress in prevention of risks through the safety planning and simulation. This collaborative safety planning and predictive risk awareness within construction the projects are to become the starting points to combining general technical planning with novel safety management functions.

Through scoping literature review the study of emergent technologies application for the occupational health and safety in BIM-related construction projects has been carried out. The main finding of this research is a proposal of BIM-based digital twins' frame-work able to enhance strategic developments of proactive solutions of safety planning and management in construction industry. BIM-based digital twinning facilitates to overcome the employees' resistance and to improve safety management related communication that is considered the reason for construction relatively high ratios of accidents. BIM-based digital twins are advanced and flexible enough to give decision-making support in the scope of complex situations and comprehensive data management of construction projects. The initial conceptual framework of correlations among Safety Management processes, general strategic decision-making on a project level, BIM-based digital twins and Decision Support System, is outlined.

As well as the BIM-based digital twin framework for decision-making of safety management has been outlined applying the Research through Design. However, the future in-depth strategic analysis of BIM-based digital twin as a decisive factor of decision-making in safety management will be required to determine functional model suitable to be implemented on executive level of construction companies.

Keywords

Building Information Modelling, digital twins, decision making, Occupational Health and Safety, safety management



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1. Introduction

The occupational risks and workplace injuries are still worldwide problems when occupational health and safety (OHS) in building construction considered (Melzner et al., 2013). The growing degree of digitalization in the construction industry as well as the emergent management methods like Lean Construction (Antillón, 2010), enhances the development of new strategies and methods focused on the OHS improvement. However, Industry 4.0 technologies' implementation in the construction holistic system of management is still scarce. Like several other industries in the construction branch, Risk Management and safety planning are considered as a key factor of production/execution planning (Li and Guldenmund, 2018). Nevertheless, this safety planning is generally performed separately from the building project design and in a broad gap from the technical planning phase.

Building information modelling (BIM), virtual reality (VR), and mixed reality (MR) are good examples of touchpoints of future strategies already planted within the functional area of Occupational Security and Safety as operative instruments. The effective implementation of emergent digital approaches, in particular hybrid or mixed models, requires the overall statement of performance indicators for decision-making processes both general Management and Risk/Safety Management.

Originally designed to facilitate technical information of construction project, the BIM-based digital twinning heads to become the key factor for more collaborative and efficient risk evaluation and safety management during all construction phases of a building's life-cycle and at all organizational levels. Even considering the applications of BIM in different areas of building design and construction planning are increasing rapidly (Zou et al., 2017), the effective cohesion between the most innovative technologies applicable into risk management and technical construction planning requires a more proactive approach (Brocal et al., 2017). Some authors (Sharmanov et al., 2020) provide even specific methods of control and security index establishment to estimate influence of dangerous production factors, all using the BIM information. While most BIM assessment applications undertake the safety challenges in the construction (Fargnoli & Lombardi, 2020), some of appliances aim at different industries (Abed et al., 2020; Khan et al., 2019). All these approaches have in common how to use BIM-based information to react quickly in situation of emergent risks in the workplaces.

On the other hand, the digital twinning in safety management is gradually becoming a widely accepted term within many industries worldwide (Lee et al., 2019). It is broadly anticipated to provide huge technological and procedure shifts of risk management in the construction industry as well. A digital twinning of the construction

environment provides a virtual simulation of construction place as well as it develops intrinsic opportunities to identify the construction environment safety problems (Hou et al., 2021; Li et al., 2018)

This work delves into BIM-based and digital twinning related safety management convergence (Geum et al., 2016). It will provide a preliminary predictive model of decision making and feedback process. As a conceptual model of internal process management, it is necessarily based on proven approaches within and outside of the building construction industry.

2. Theoretical Background

Present research carries out the scoping literature review and the analysis of sectorial studies on emergent applications of BIM, Digital Twinning (as one of the scopes of Augmented Reality) into the Safety Management in general and into Construction, in particular. This scoping review confirms generally recognized two main approaches for improving construction safety and security: the proper collaborative planning and sufficient awareness (Benjaoran and Bhokha, 2010).

The following state-of-art analysis looks for the confirmation of scientific and practitioners' interest in the emergent technologies consolidation within the safety management processes.

The BIM techniques have been widely used in the construction safety planning. Accordingly, and with the visualization technologies evolution, BIM also has found application to solve construction safety issues, including risk recognition and prevention, as well as workers safety trainings (Howell and Rezgui, 2018). The 4D BIM models can provide stakeholders with construction details and, as a result, to develop more accurate and intuitive risk detection scope (Akram et al., 2019). Through the machine learning application the Safety Managers can establish, according to the safety regulations and construction data, the framework that links the information processed within BIM and convert it into the visualization and virtual mapping and simulation. By this mapping of BIM information along with risk management rules, the "hot points" of hazards can be identified almost automatically during project and construction phases of edification (Cortés-Pérez et al., 2020).

On the other hand, the concept of digital twinning or digital twins, comprises creation of digital mirroring replica aimed to, through synchronized data streams, monitor and optimize the performance of physical object (Batty, 2018; Schleich et al., 2017). In recent years, digital twinning has achieved wide application in different industries, in particular in complex and risk dependent industries. The smart building trend in construction has opened ample perspectives for digital twins implementation within different parts of building project

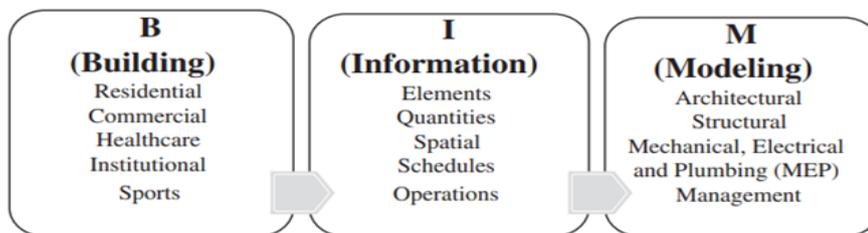
and construction execution. Also, smart city approach has gradually spread the digitalization of construction processes and procedures including digital twins (Austin et al., 2020).

2.1. BIM-based Digital Twinning and Safety Management in Construction Industry. State of Art

The integration of BIM and digital twinning technology may become the key factor to perform real-time dynamic information processing and may mean a big step into the application of advanced methods such as Internet of Thing or Predictive Big Data Analysis in many construction processes (Sai et al., 2020). However, the common managerial ground is required to study the BIM-based Digital Twin potential (Simpson, 2015).

BIM is a process for creating and managing a digital model composed by specific asset information alongside its whole life-cycle (Doubouya et al., 2016) as well as it generate coordinated digital dataset necessary to operate the construction project (Peng et al., 2017). Considering that all stakeholders who interact with the asset management, can be eligible for the task or process improvement (Kent and Becerik-Gerber, 2010), the integrated BIM-based construction management raises interest of both academics and managers. One of the principal outputs of all dataset processing is the building information model extracted from the information assembled collaboratively and updated at main stages of a project. This information, beyond the technical and structural planning, provides valuable input for wide range of managerial decisions, including the Risk and Safety Management (Zhang et al., 2013).

Figura 1 A visual representation of BIM concept (Cerovsek 2011).



Present interest of construction professionals around the BIM applications has opened the opportunity window for new proposals of accelerating the implementation as one of decision-making systems (Hardin, 2009) This attempts have put the attentions of various aspects of BIM use, such as the simulations and trainings through the interactive learning environments and visualization (Alshawi et al., 2007); analysis and predictive models of certain conditions, in particular identifying the hazards and unsafe operation dynamics (Rozenfeld et al., 2009); facilitating reporting of project status and switch controlling system (Sacks et al., 2009); enhancing the all level communication and collaboration (Hakkarainen et al., 2010) and monitoring of status and conditions through the augmented reality technologies (Cheng and Teizer, 2013) in particular the Internet of Things related, digital twinning (Lu et al., 2019).

Digital twinning, a recent concept, is gradually gaining more and more relevance within the model-based systems engineering (MBSE) (Haag and Anderl, 2018; Madni et al., 2019) Considering digital twins, closely related to the progress of Internet of Things, as a dynamic digital representation of real-world systems (Uhlemann et al., 2017), their potential industrial applications are almost infinite (Kritzinger et al., 2018). Digital twin permanently updates the operational information on the system's performance, maintenance, and efficiency status throughout the physical system's life cycle (Austin et al., 2020). This information, beyond the

technical and structural planning, provides valuable input for wide range of managerial decisions, including the Risk and Safety Management (Zhang et al., 2013). However, only little automation in modelling and planning of safety processes has found direct application into the industrial operations so far. Subsequently, the scope of the digital twins in construction industry incorporates the vision of business, context, and sensor-gathered data precedent from physical systems (or processes). Within the dynamic environment and technical complexity of construction projects, the virtual system model of the digital twin is focused on analysis facilitation, enabling of real-time monitoring of systems and processes and intelligent, even predictive, operations' improvement roadmaps (Liu et al., 2019).

Current interest in BIM-based digital twinning is gradually reaching the field of occupational health and safety management (Sai et al., 2020; Wang et al., 2014). As first pilot integrations has gained widespread attention in construction industry (Cerovsek, 2011; Cooke et al., 2008). Using BIM-based approach to virtual and digital models of a building can result in solutions that facilitate the engineering control and predictive safety management as a part of business decision making (Guo et al., 2013). Technologically, BIM-based digital twins can be introduced as a digital simulation interactive interface of building information model related to project planning, design, construction, or operation (Azhar, 2009; Sai et al., 2020). On the other hand, from

a process scope, BIM-based digital twinning can optimise the building lifecycle, reduce costs and improve efficiency through encompassing all operational systems within building project with a digital model that enables accurate information processing (Kim and Teizer, 2014; Madni et al., 2019) and peer-to-peer collaboration among all stakeholders (Faghihi et al., 2014). Therefore, a new integrative research approach is required to delimit the specific applications of BIM-based digital twinning into Safety Decision-making in building construction.

3. Method

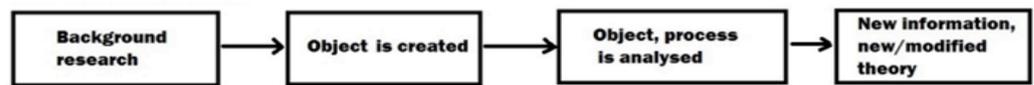
This research has conducted the scoping review of concepts of BIM-based Safety planning, BIM-related digital twinning, BIM applications into Lean Construction.

This study presents the preliminary results on the advances in the research aimed to the combined decision-making process of Safety Management through the implementation BIM-based digital twinning. This research focuses on the preliminary conceptualization of different areas of Safety Management unit in building construction industry enhancing emergent VR technology on the basis of BIM-originated data. It is expected, after scheduled future phases of the study, to be able to determine the take-up optimal decision-making pathway for Safety Management.

Equally important, the present study develops an overall non-exhaustive review of the state of art of BIM-based digital twinning for Safety Management purposed. Firstly, the search process has been carried out in the main scientific databases such as Web of Knowledge, Science Direct or Google Scholar since they are identified as relevant to the research domain. Secondly, the qualitative process for document filtering has been performed. The filtering variable of a number of previous citations and accurate adjustment to present research scope have been established as preferent.

The model of safety management process proposed has been developed applying the Research through Design (RtD) method. This method has been applied in the specifications gathering, system prospection and the experts' validation (Godin and Zahedi, 2014). RtD is a method that is used increasingly both inside design, architectural- and engineering-design research (Verbeke and Pak, 2013). Even if, according to Zimmerman et al. (2010) theory-building is the weak aspect of RtD approach in this case can be considered sufficient as a specific context is involved. Current research aligns perfectly with RtD approach as it attempts to re-value common practice (Grand and Jonas, 2012) and it proposes new conceptualization (Stappers and Giaccardi, 2017)

Figura 2 Research through Design. Framework (Koskinen et al., 2011)



4. BIM-based Digital Twinning supported Decision-Making in Safety Management

The decision making related to the Safety Management in complex projects such as building construction, requires the most relevant content being effectively spread among concerned stakeholders. The content creation in BIM-based digital twin systems are not limited to desktop interfaces, it can be extended through digital devices to all users as well as it can be presented in different mode including augmented reality, virtual reality, mix reality, 3D printing and many others. This approach enhances the flexible and ad hoc adjustments all over the work procedures. However, the additional advantage of complex and interactive BIM-based digital twinning is the bidirectionality and the decentralisation of asset management within the operations and maintenance stage of project. The challenge to implement of BIM-based digital twin within the occupational health and safety systems is multifaceted and with one of the key objectives to capture,

exchange, use and management of information throughout a whole-life-cycle of the project.

Fig.3 represents the framework of the process of safety decision-making closely entwined with BIM-based digital twin. This proposed perspective framework of the BIM-based digital twin of decision-making in safety management has potential to improve the safety planning and the risk management in building construction projects (Zhou et al., 2012). In order to reduce the degree of uncertainty, any data processing instrument, developed in the form of a Decision Support System (DSS), is closely linked to the existing and reliable data input from BIM digital twinning settings. It requires normalised and well-defined performances metrics and leverages based on pre-defined KPIs and specific requirements of Safety Management Processes. Accordingly, the joint use of the BIM digital twinning and the DSS, allows Safety Managers to make more conscious and data-based decisions. As the safety planning can be considered as high impact dimension of the construction operational planning,

the most efficient real-time information processing is a key challenge due to context and projects' complexity. Most of safety management processes can be directly and two-way related to BIM-based digital twin system. The advanced decision support system based on BIM-based digital twinning encompasses potential for reaching new performance level in safety and risk management.

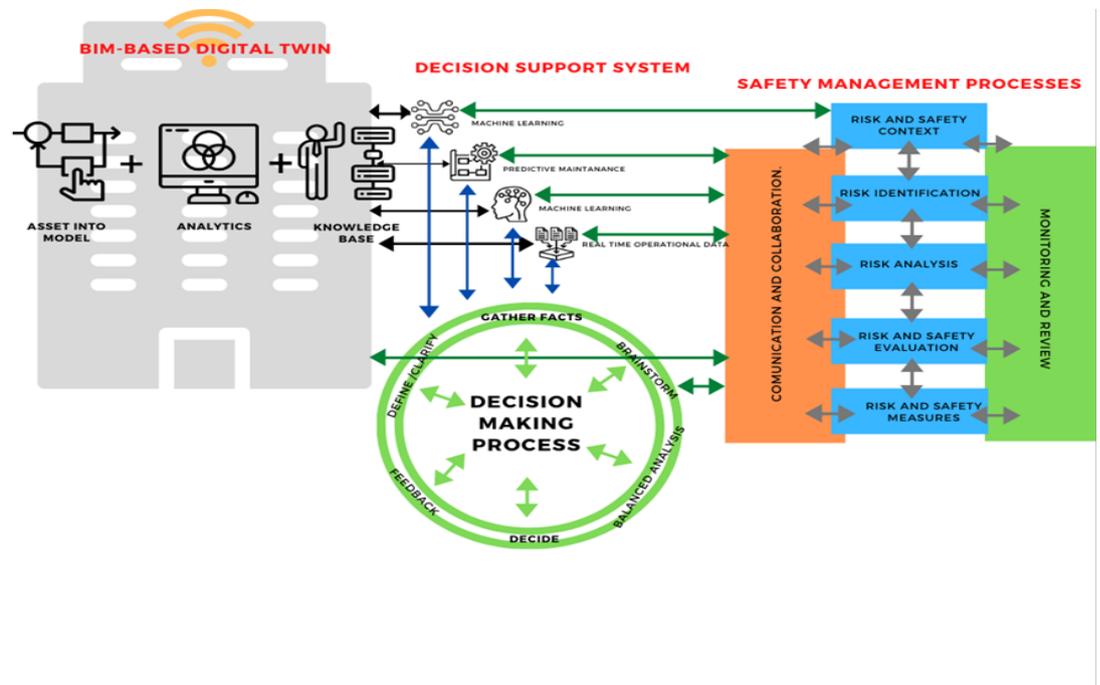
Machine learning is required to accomplish a real-time optimization of assessment process in this DSS model. The decision to execute must respond to the prevention and predictability features of data-based Safety Management. In fact, the DSS pathway is the central piece of this complex system. It plays the role of both the nexus between BIM-based digital twins and Safety Management information repositories, and the determinant conductor of key information directly toward the decision-making units.

Furthermore, as the occupational health and safety management is a multi-dimensional field (Hinze et al., 2013), the communication and feedback to the level of employee should be considered within the BIM-based digital twin as a support to all decision-making processes and operational performance. BIM-based digital twinning

facilitates to overcome the employees' resistance and to improve safety management related communication that is considered the reason for construction relatively high ratios of accidents. BIM-based digital twins are advanced and flexible enough to give decision-making support in the scope of complex situations and comprehensive data management of construction projects.

Hence, the BIM-based digital twinning for Safety Management can be the logical transition towards a cyber-physical integration system and VR application in whole organization decision-making processes. The intelligent optimization, as a one of main aims of digitalization processes, need to maximize the optimal solution findings when workers' security and safety concerned, in particular, if bounded to risk-related constraints (Pan and Zhang, 2021). The optimization is a key feature of any decision making across the whole lifecycle of a complex construction project. It has special consequences when risks and construction workplace hazards requires the optimization-based Safety Management approach. And the physical, real-world system is too convoluted to be able to maximize the labor stability and safety through P2P supervision or surveillance.

Figura 3 Proposed Framework of the BIM-based digital twin within decision-making of safety management.



5. Conclusions and future work

Through the integration of BIM technology and digital twin technology, the optimization and all-processes decision-making support system can improve results of safety management in construction industry. Nowadays this industry, in particular in Spain, is evolving into a highly profitable economic activity. The real-time interfaces that facilitate the information sharing and they generate valuable input for decision-making, are the step towards safety management based on predictive analysis, all users/workers inclusion, and smart assets optimization. Recent evolution of BIM-based digital twins is providing milestone for the strategic developments of pro-active solutions of safety planning and management in construction industry. Current research is still a work in progress project includes in the study of emergent technologies application for the occupational health and safety in productive industries. The main finding is the BIM-based digital twin framework within decision-making of safety management.

This proposed framework, although many shortcomings are envisioned within the initial version, consists of the data and information streams between BIM-based digital twin and safety management processes; all this with special focus on the capability to facilitate or assess the decision-making processes at all organizational levels. Furthermore, this framework places special emphasis on supporting the end-user, operator, and maintainer engagement at the easily stages within the design phase to capture their requirements.

The future in-depth strategic analysis of BIM-based digital twin as a decisive factor of decision-making in safety management is needed. The further development of specific concepts and empiric real practice is advisable as well. This future research should be conducted to confront the alignment of the proposed framework with real construction projects contingencies.

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