BIM, IoT AND MR INTEGRATION APPLIED ON RISK MAPS FOR CONSTRUCTION

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Abstract. In Brazil, the Architecture, Engineering, and Construction (AEC) industry is a high-risk segment that accumulates workplace injuries. National standards concerning Risk Management in construction require the production of Risk Maps, aiming at increasing users' awareness about risks and hazards on site. However, the traditional process of implementing Risk Maps has limitations that reduce their efficiency in a real application. The adoption of innovative technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Mixed Reality (MR) may benefit communication resources of Risk Maps and improve Risk Management. This paper presents a conceptual framework of Risk Management for the construction phase to achieve a Dynamic Risk Map using BIM, IoT, and MR technologies. Also, this paper presents a proof of concept based on the framework proposed. The methods include (i) identifying Risk Maps limitations; (ii) mapping their traditional process to integrate innovative technologies; (iii) creating a framework for supporting Risk Maps improvement; and (iv) simulating Dynamic Risk Maps concerning tracking, sensing, and exhibition resources. Research outcomes highlight that the dynamic status of a Risk Map increases feedback capabilities regarding predicted and actual risks on site and context awareness. That increase is due to communication enrichment and the assurance of inspection activities based on prevention through design and real-time monitoring.

Keywords: Risk Management, Risk Maps, BIM, Internet of Things, Mixed Reality.

1 Introduction

Risk Management in Architecture, Engineering, and Construction (AEC) industry is a global issue. According to [1], failure to handle risks appropriately may not only lead to challenges in meeting project purposes but also reflects on the future growth of cities. In Brazil, the Ministry of Labor and Employment [2] considers the AEC industry as a high-risk segment, due to the distribution of labor accidents by economic sectors. Brazilian Federal Government's historical database of accidents, when restricted to Building Construction, reinforces those statistics, as exhibited in Figure 1.

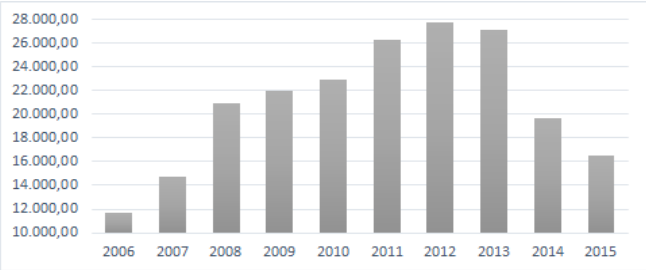

Fig. 1. National Quantity of Civil Construction Work Accidents.

Considering such a scenario, Brazil has regulated the NBR ISO 31000 as the national standard for Risk Management. That standard defines Risk Management as a set of coordinated activities that directs and controls an organization regarding risks [3]. Risks comprise time overruns, economic risks, industrial conflicts, and workplace injuries [4]. One Brazilian Regulatory Standard concerning the prevention of workplace injuries is the NR5: Internal Commission of Accident Prevention (CIPA). The NR5 prescribes the Risk Map as an essential tool to prevent workplace injuries since its graphical resources represent the risks and hazards of a particular environment.

Despite the prescription of Risk Map as an essential tool, there are several limitations in its production and delivery, ranging from planning, the graphical representation itself, until the applied methods and context-based updates. In short, CIPA has challenges in conceptualizing a Risk Map, which reflects on the information exposure, visualization, and understanding concerning the potential user [5]. Besides, its implementation is still a manual undertaking as well as its decision making is frequently based on knowledge and intuition - decreasing efficiency in the real environment [6].

Otherwise, changing in technological, technical, or standard resources may reduce the number of workplace injuries [7]. In that sense, according to [1], the interest and adoption of Information and Communication Technologies (ICTs) for Risk Management have increased. Recognizing that trend, this paper considers that the use of ICTs by CIPA in Brazilian circumstances may enhance the traditional process of Risk Map, lowering current issues and assuring prevention to risk and hazard in the AEC industry. We assume that ICTs such as Building Information Modeling (BIM), Internet of Things (IoT), and Mixed Reality (MR) have resources that can directly support communication, comprehension, and access to Risk Maps.

Previous studies such as [1] identified gaps concerning the integration of BIM and related digital technologies with traditional methods, processes, and techniques of Risk Management. Moreover, there is a need for combining BIM-based and traditional Risk Management to improve practical applicability. Hence, this paper proposes a conceptual framework of Risk Management for the construction phase to achieve a Dynamic Risk Map using BIM, IoT, and MR technologies. Also, we present the proof of concept based on the framework proposed. The authors expect that ICTs adoption and the dynamic status of a Risk Map may increase the effectiveness of its planning and implementation, and contribute to the practical reduction of accidents at the construction site.

2 Context

As previously highlighted, risks and hazards in the construction phase are recurrent [8], which transforms the AEC industry in one of the economic sectors that registers the most accidents in Brazil. The traditional Brazilian process of Risk Management for construction requires an Internal Commission of Accident Prevention regulated by NR5. CIPA also responds to requirements of ABNT NBR ISO 31000 and other Regulatory Standards such as NR18, for assuring safety in the work environment. Furthermore, the commission has the support of the Specialized Services in Occupational Health and Safety (SESMT). CIPA composition usually involves building representative stakeholders such as consultants, clients, designers, the construction team, and others. The Commission's main role is to define practical tools for achieving effective Risk Management. One of those tools is the Risk Map, which supports education, mainly among the construction team, comprising risks and hazards on site. That support is based on controlling, reducing, and eliminating workplace injuries [9]. Figure 2 synthesizes that traditional process.

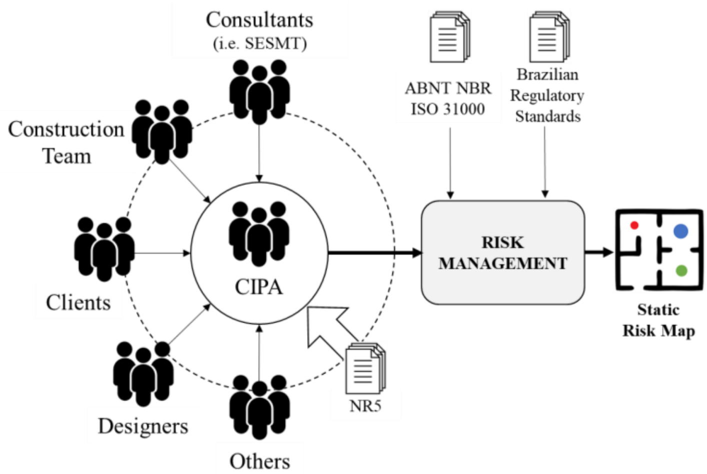

Fig. 2. Brazilian Risk Management in Construction Phase.

Risk Map is a graphical representation of the work environment (i.e., construction site's floorplan) with its risks and hazards. That conjunction usually follows as standardized annotations: (i) the risk groups by room, considering their agents (e.g., physical, chemical, biological, ergonomic and accident) and related causes; (ii) the degree of intensity for each group, according to worker's perception of risk; and (iii) the number of workers exposed to the predicted risks [10]. Graphically, the risk groups comprehend mark-ups such as circles combined with color patterns (e.g., green, red, brown, yellow, and blue), sizes, and quantities regarding risk magnitude (Table 1).

Table 1. Brazilian Risk Map Standard.

Agents	Degree of intensity			Causes	Examples
	Little	Medium	Big		
Physical	●	●	●	Forms of energy	Noise, vibration, abnormal pressures, extreme temperatures
Chemical	●	●	●	Substances, compounds or products	Gases, vapors and mists
Biological	●	●	●	Microorganisms	Bacilli, bacteria, fungi, protozoa, parasites, viruses
Ergonomic	●	●	●	Psychophysiological characteristics	Heavy physical work, incorrect postures, uncomfortable positions, repetition, monotony, excessive rhythm
Accident	●	●	●	Inappropriate physical arrangements	Defective, inadequate or non-existent machinery, equipment and tools, danger of fire or explosion

Considering the concurrent changes related to the construction environment, Risk Maps, despite their static resources and 2D format, should attend to more than one construction stage. That attendance in the traditional process includes the removal or decrease of circles or their features (i.e., size or quantity). Furthermore, [10] recommends the location of Risk Maps at accessible areas to facilitate the construction team's awareness of risks and hazards.

Recognizing the limitations of Risk Map's traditional process, [11] states that for ensuring a safe and unsurprising work environment, there is a demand for adopting innovative technologies. In that regard, we believe that the increasing adoption of BIM in AEC industry, as well as its potential extension and link to MR and IoT technologies, should be explored to assist Risk Maps.

BIM is a technology that plays a significant role in Risk Management during the Construction and Maintenance of a project since it enhances efficiency regarding safety through the exploration of dynamic visualization resources [12]. BIM benefits in that context involve the use of BIM 3D Model's main features, which facilitate risk identification and communication for accident prevention [13-14]. Besides, BIM Model uses to comprehend the possibility of risk and hazard assessment [15] supporting the prevention through design approach [16]. In short, potential applications of BIM for Risk Management concerning construction phase may include: (i) the association between BIM Model's objects and risk and hazard's types; (ii) the visualization of solutions that help in environment's safety; and (iii) the risk control proposal through BIM Model's revisions [17].

IoT is a paradigm defined as a dynamic global network infrastructure [18] that links real objects and beings with the virtual world and environment, enabling connectivity in any place, anytime, not only for anyone but also for anything [19]. In IoT, "things" exchange sensing data and information about the environment, while reacting to the real-world events and influencing it by running processes that trigger actions, create and deliver services [18]. [15] indicates a BIM/IoT Interfacing in which the BIM Model is connected to that IoT network and benefited from real-time data provided by monitoring and control (e.g., Wireless Sensor Network - WSN) as well as tracking and tagging (e.g., Radio Frequency Identification – RFID, Near Field Communication – NFC, Bluetooth Low Energy - BLE) technologies. Concerning Risk Management and BIM/IoT Interfacing, [20] present solutions of real-time environmental monitoring for confined spaces and hazardous zones. Moreover, [21] and [22] demonstrate the monitoring and control of security violations on construction sites. Finally, [23] explores BIM Model's for identifying risks and displaying actual data.

Mixed Reality involves the merging of real and virtual worlds. It is considered the area between the two extremes, where both the real and the virtual are mixed. Virtual reality and augmented reality are part of Mixed Reality and works together in *reality-virtuality continuum* [24]. Virtual Reality (VR) is a computational interface that involves simulation in real-time [25]. VR has the characteristic of virtual environments visualization and interaction with objects by the user, in addition to stimulating the other senses such as touch and hearing [26]. Augmented Reality (AR) connects computer-generated objects in a real environment, in real-time. AR can apply to all senses, such as vision, hearing, and smell [27]. Concerning Risk Management and AR, previous studies present, for instance, applications involving emergency response regarding AR-based mobile escape guidelines applied to self-evacuation [28], as well as segment displacement inspection during tunneling construction, using AR-based system superimposed with BIM Models into the real structure [29]. Nevertheless, regarding Virtual Reality (VR) and its relation to safety learning in construction and engineering, [30] highlights research gaps in Risk Management stages such as risk evaluation, risk response planning, and risk monitoring and controlling.

Therefore, Risk Management is a potential area to integrate Mixed Reality with BIM Models and IoT technologies. The integration benefits may embrace the visualization of the Risk Map superimposed in the real work environment with not only predicted risks by CIPA but also actual risks provided by real-time monitoring. After identifying Risk Maps limitations, mapping the traditional process, and evaluate the potential of integrating innovative technologies, it was possible to propose a framework of Risk Management for producing Risk Maps based on the benefits of BIM, IoT, and MR (applying augmented reality and virtual reality technologies). Those resources may enhance the communication of Risk Maps aiming at reducing risks and hazards in construction sites. As following, it was presented two conceptual simulations of the framework considering tracking, sensing, and exhibition resources.

3 A framework integrating BIM, IoT and Mixed Reality

Regarding the gap of integrating BIM and related digital technologies with the traditional framework of Risk Management, we identified the potentiality of inputting resources of such technologies in the product itself: the Risk Map. As a result, we suggest transforming the Risk Map that has static features in a Dynamic Risk Map aiming at providing an interactive and accessible visualization (Figure 3).

The interface between these technologies has different approaches: BIM and MR may share 3D Models and building-specific information that will be organized and exhibited using an established device. MR and IoT may interface with each other using sensor-based tracking for activating the visualization and/or through the exhibition of real-time data collected by IoT solutions.

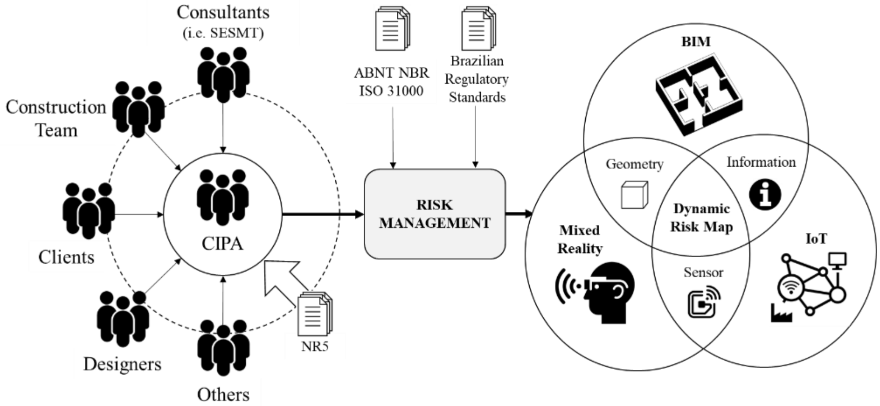

Fig. 3. BIM-based Risk Management integrated with IoT and MR in Construction Phase.

Finally, BIM and IoT may be integrated through the association of virtual building data and actual data, respectively, and/or inputting that actual data in 3D Models for geometric and semantic contextualization. The simulation of these integrated technologies is highlighted in the next framework presented in Figure 4.

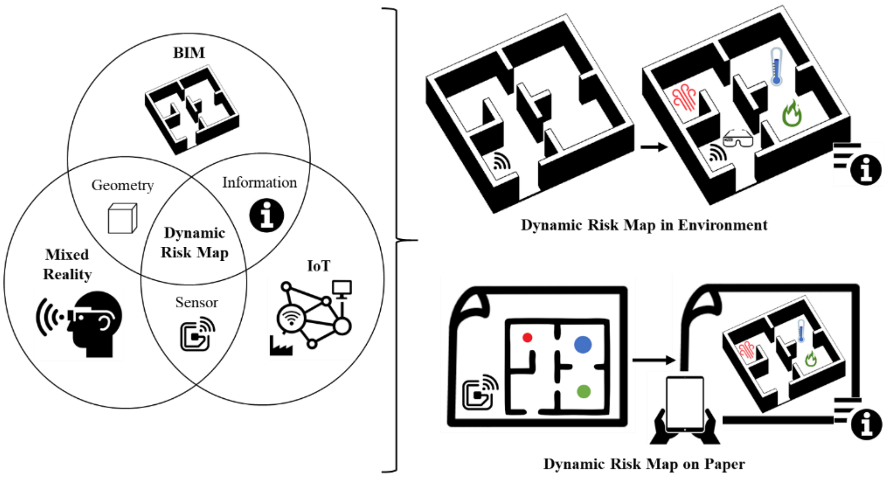

Fig. 4. Dynamic Risk Map: visualization Forms.

The Dynamic Risk Map in Environment is a condition in which users can access each construction zone with a display device (e.g., smart glasses, tablet, smartphone) to visualize within a system application the sorts of risks predicted by CIPA. In this case, the risk map is visualized with Augmented Reality technology, and it is localized on each floor, as recommended by CIPA, and also individualized in each room. Concerning the risks themselves, their visualization is through 3D symbols related to each predicted risk, colored according to the group risk pattern defined by NR5. In turn, the BIM Model is displayed in the natural environment and scale (1:1), becoming essential for contextualizing the risks through geometric visualization of the several construction phases identified in the 4D dimension. Construction phases can be previously inputted into the system for later access and AR visualization. Thus, it is possible to comprehend the construction status of geometrically and predicted risks by CIPA associated with that specific phase.

Besides, users can also visualize actual risks due to sensor-based information feedback provided by an IoT solution. Sensors in that scenario are defined from CIPA predicted risks and installed in each related local. In Table 2, we present an association between CIPA Risk Factors and Sensor Types regarding that situation. For instance, in a zone that has risks of high temperatures (e.g., confined spaces), CIPA may require an IoT solution that collects temperature data in real-time and delivers warnings based on indicators of risk and hazard. It is a situation of context-awareness.

Table 2. CIPA Risk Factors and Sensor Types correlation.

Risk Group	Agents	Causes	BIM Objects	IoT Sensors
Group I	Physical	Forms of Energy		Temperature, Humidity, Pressure, Microphone, Water Detection
Group II	Chemical	Substances, Compounds or Products		NO2, SH2, CO, CO2, Hydrocarbons, CH4, O3, Ultraviolet (UVA, UVB)
Group III	Biological	Microorganisms		Not identified
Group IV	Ergonomic	Psychophysiological Characteristics		Not identified
Group V	Accident	Inappropriate Physical Arrangements		O2, H2, CH4, Ethanol, Isobutane, Accelerometer

MR tracking for visualization in that context can be practiced through the use of fiducial markers or sensors. Considering fiducial markers, images previously registered in the system application will activate a model visualization by the user's activity of scanning. Regarding the second possibility, sensors will activate the visualization during the detection of the user's and/or display device's presence by technology such as RFID, NFC, or BLE. Regarding both types of markers for MR tracking, any display device mentioned above can be utilized.

The Dynamic Risk Map on Paper is a condition in which the 2D Risk Map is already localized in a strategic place of the construction environment, and the users can utilize a display device to visualize within a system application the predicted risks. That risks are contextualized in a 4D BIM Model following its scale and exhibited in Virtual Reality. In this scenario, users can also utilize a tracking system through a fiducial marker or sensor to activate the application. The risk representation is the same as in the case of the Dynamic Risk Map on Environment, that is, symbolic objects representing risks with colors related to their group risk considering NR5 standards. That application enhances the user’s awareness of risks and hazards and gives an overview of the construction environment. In item 4, we will present the proof of concept for the Dynamic Risk Map on paper.

4 Application

The application was developed using a BIM Model (Figure 5) of the Faculty of Architecture at Federal University of Bahia (FAUFBA) annex building (Figure 6), located in the Federação district in Salvador, Bahia. The building has four floors, a mixed structure (concrete and metal), is under construction and is expected to be completed by the end of 2020.

The BIM Model (Figure 6A) was developed in the authoring application Autodesk Revit 2018, the BIM/IoT interfacing was designed in the BIM middleware solution Dynamo and the MR application was created with Autodesk Revit Live. The Revit Live opened a connection between the authoring environment and an engagement viewer for users that can be distributed in desktop and mobile devices.

Fig. 5. FAUFBA annex building.

The authors developed a proof of concept using the Risk Group I (Table 2) and a desktop device. The goal was the Dynamic Risk Map simulation considering the resources of tracking, sensing, and exhibition through the verifying of sensor data and its visualization in virtual reality.

For this prototype, an IoT platform database was used to register environmental data (e.g., temperature and humidity) collected by a sensor network. A script (Figure 6B) was developed through Dynamo to retrieve sensor data, get the last value of each reading by room, and through a conditional statement, write these values with an alert to specific object parameters.

The adequacy of the Record Model involved the settings to build shared parameters (Figure 6C) with this aim. The script also considered inserting the symbolic risk objects modeled as generic types by room based on the values.

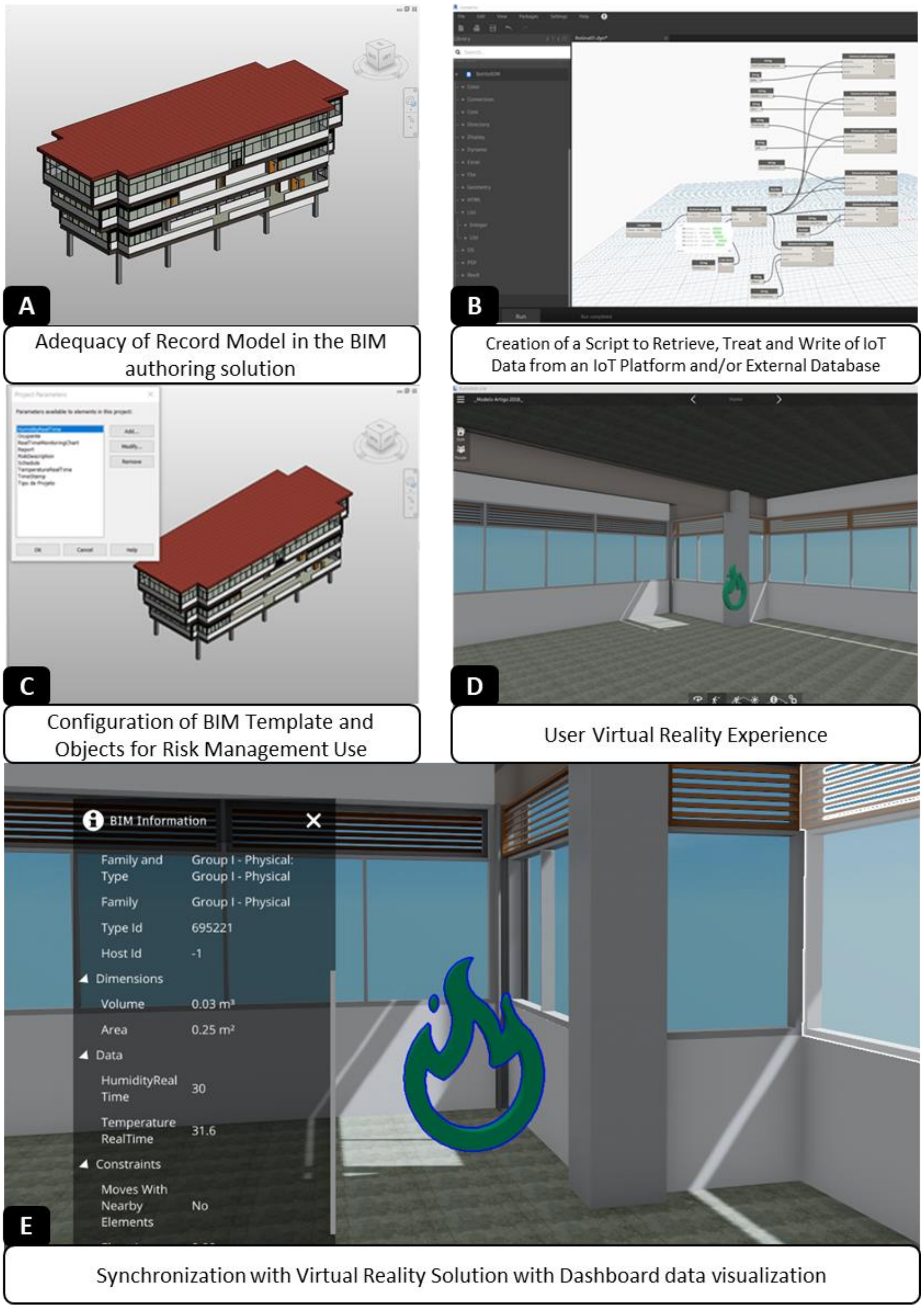

Fig. 6. Dynamic Risk Map on paper developing process.

Considering the validation of these first steps, with the BIM/IoT interfacing working for Risk Management purposes with a periodic script running, the next goal was to synchronize the updated 3D view sets from the BIM authoring environment to the MR solution (Figure 6D). A MR solution is essential to share information among non-BIM users, especially those with a mobile device on-site. The synchronizing depends on the software and can be user-based or through automation programming to achieve live status. The actual 3D view set with IoT and risk data was synchronized with Autodesk Revit Live to be accessed by any desktop device or mobile application (Figure E). According to the risk results, the risk symbols were viewed in different scale following the standard and their IoT data consulted through the properties browser. As mentioned before, regarding the degree of intensity in Table 1, the bigger the symbol, the bigger the risk of the user. With real-time presentation data (MR synchronization), users can access quantitative risk information. Besides, one of the limitations of this prototype was the no success to insert textual parameters in the 3D symbol.

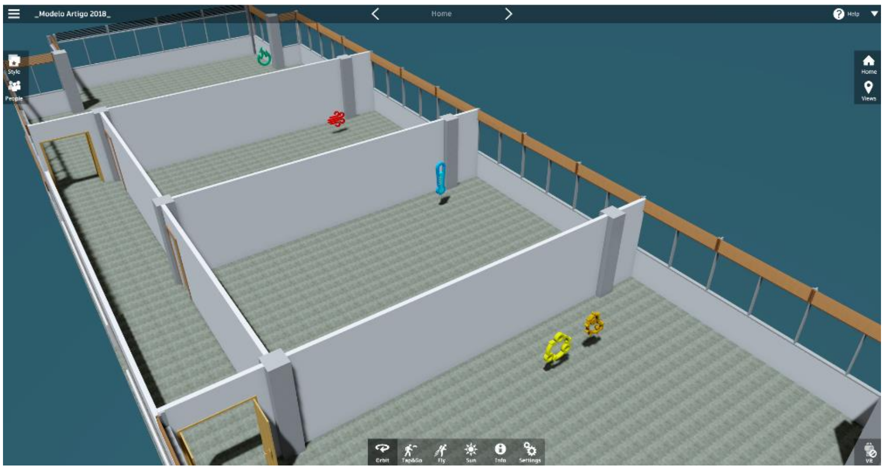

Fig. 7. Risk symbols on the environment.

5 Conclusion and future work

Concerning the gaps identified in previous studies comprising the creation, understanding, and visualization of Risk Maps as well as techniques for improving Risk Management, this paper presented a conceptual framework integrating BIM, IoT, and MR with a proof of concept. That integration considered Risk Management in the Construction phase. We presented the framework involving the relations between BIM Model and MR technology through geometry, IoT, and MR technologies through sensor-based information and/or sensor-based tracking; and BIM Model and IoT through the contextualization of actual data. These relations were highlighted in two simulations derived from the framework: a Dynamic Risk Map in Environment and a Dynamic Risk Map on Paper. In the first one, users can visualize, in Augmented Reality, both risks predicted by CIPA and actual risks provided by IoT solutions by room in a construction zone. Risks are contextualized by BIM Models on natural scale. In the second one, users can visualize, in Virtual Reality, only predicted risks in an overview of the construction zone. Risks are contextualized by BIM Models superimposed on paper following the scale of the traditional 2D Risk Map. In both simulations, the visualization is in Augmented Reality to increase awareness about the surroundings, which should make the system application adaptive and intelligent. Concerning actual risks for the Dynamic Risk Map in Environment, we also presented an association between risks grouped by CIPA and types of sensors. Finally, a proof of concept was carried out to validate the Dynamic Risk Map on Paper framework created. Besides, the IoT information was linked with success to the Record Model by an authoring tool. From that link, new risk symbols were shown by risk map group concepts. Concluding, the frameworks developed in this paper, with a proof of concept, will help the CIPA team in the planning and implementation of Risk Maps for Construction and Commissioning phase. The benefits include the rising awareness of risk and hazard on-site as well as the reduction of workplace injuries. The framework brings a potential for future work aiming at implementing these proposed systems for AR sensors solutions and measuring their performance through interviews with users and safety indicators.

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