MANTRA: Enhancing Worker Safety through an Integrated BIM-IoT Mobile Application

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Abstract. In the evolving landscape of construction safety management, the integration of Internet of Things (IoT) and Building Information Modeling (BIM) technologies [1] presents a novel approach to addressing the dynamic challenges of workplace safety. The MANTRA project, developed under the ASSIST-IoT H2020 (Horizon 2020) project [2], introduces an innovative hybrid mobile application designed to enhance the safety of construction workers by providing real-time, interactive visualization and management of temporary danger zones on construction sites.

This paper outlines the development and implementation of MANTRA, focusing on its integration of BIM for detailed site representation and ASSIST-IoT platform for real-time data exchange and alerts management. The application enables workers to identify and mark danger zones directly on digital site models, significantly improving the timeliness and accuracy of safety warnings. By leveraging cross-platform compatibility through Progressive Web App (PWA) Framework [3], MANTRA ensures widespread accessibility and usability.

Preliminary results from field tests and lab evaluations demonstrate MANTRA's effectiveness in improving situational awareness and reducing the risk of accidents. The application not only streamlines the process of marking and communicating hazards but also promotes a proactive safety culture.

MANTRA's contribution to construction safety represents a significant advancement in digital technology application, highlighting the potential for IoT and BIM integration in risk management and worker safety enhancement in dynamic work environments.

Keywords: Internet of Things (IoT) · Building Information Modeling (BIM) · Hybrid Mobile Application · Construction Safety · Real-Time Data Exchange · Situational Awareness

1 Introduction

1.1 Context

The construction industry, characterized by its dynamic and hazardous environments, has long faced challenges in ensuring the safety and well-being of its workforce. Traditional safety management practices, while foundational, often fall short in addressing the rapidly changing conditions on construction sites [4]. The advent of digital technologies, specifically the IoT and BIM, presents a transformative opportunity to enhance safety protocols and practices in this sector.

IoT, with its network of interconnected sensors and devices, offers unparalleled capabilities in monitoring and communicating real-time data. This technology is crucial in construction sites where conditions can change rapidly, and the timely dissemination of information can be the difference between safety and hazard [5]. BIM, on the other hand, provides a detailed digital representation of physical and functional characteristics of construction projects. When integrated with IoT, BIM can serve not just as a planning and management tool but also as an interactive platform for site safety and risk management [6].

Despite these technological advancements, the construction industry faces challenges in effectively integrating these technologies to address specific safety concerns. Temporary danger zones, which are areas that become hazardous due to ongoing activities or sudden environmental changes, are particularly challenging to manage. Traditional methods of marking and communicating these zones are often manual, reactive, and prone to human error [7]. Furthermore, the diverse and transient nature of construction workforces, including language barriers and varying levels of familiarity with the site, exacerbates the challenge of ensuring that every worker is aware of current dangers.

The MANTRA project emerges in this context as an innovative solution, leveraging the strengths of IoT and BIM to enhance construction site safety. The project's cornerstone is the development of a hybrid mobile application that aims to revolutionize how information about temporary danger zones is communicated and managed. By integrating real-time data from IoT devices with the interactive BIM models, MANTRA enables workers to visualize and understand the dynamic nature of their working environment accurately. This approach not only enhances the timeliness and reliability of safety warnings but also empowers workers to be proactive participants in their safety management.

1.2 The problem

Construction sites are inherently complex and fluid environments, presenting unique safety challenges. One of the most significant and persistent issues in this sector is the management of temporary danger zones. These zones represent areas that intermittently become hazardous due to various factors such as ongoing construction activities, machinery movement, structural changes, or environmental conditions.

Dynamic Nature of Construction Sites Unlike static industrial settings, construction sites are continuously evolving. This constant change means that areas previously deemed safe can rapidly become hazardous, necessitating an agile and responsive safety management system. Traditional safety protocols, reliant on manual processes and static signage, are often unable to keep pace with these changes, leading to gaps in safety coverage [8].

Communication Barriers Effective communication of hazards is crucial in construction sites, where a diverse workforce, including contractors, temporary workers, and those with varying language proficiencies, converge. The conventional methods of communicating dangers, such as verbal briefings or physical signs, are not only slow to disseminate but also prone to misunderstandings and overlooks, especially in a multilingual workforce [9].

Reliance on Human Vigilance Current practices heavily rely on the vigilance of workers and supervisors to identify and communicate hazards. This reliance introduces human error into safety management, as workers may fail to recognize a newly emerging danger or may not communicate it effectively to all parties [10].

Inadequate Real-Time Response The lack of real-time monitoring and alert systems in traditional safety approaches means that information about emerging hazards often reaches workers with a delay [11]. This delay is critical in an environment where timely information can prevent accidents and injuries.

Limitations of Current Technology Integration While there have been advances in incorporating technology into construction safety, these have often been piecemeal and not fully integrated. Solutions like standalone safety apps or basic IoT implementations provide limited functionality and fail to offer a comprehensive and interactive overview of the entire site, crucial for understanding and navigating temporary danger zones [11].

In this context, the construction industry faces the challenge of devising a safety management system that is dynamic, responsive, and comprehensive, addressing the unique nature of temporary danger zones. This system must not only provide real-time updates on site conditions but also be accessible and understandable to a diverse and transient workforce.

1.3 Proposed solution

In response to the multifaceted challenges of managing temporary danger zones in construction sites, the MANTRA project proposes a groundbreaking solution that synergizes the capabilities of IoT and BIM technologies through a hybrid mobile application. This innovative approach aims to revolutionize safety management in construction environments by providing a dynamic, interactive, and

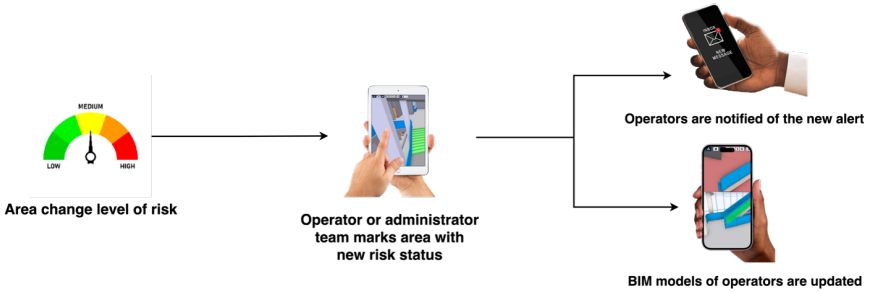

Fig. 1. MANTRA Concept

accessible platform for real-time hazard identification and communication as it is shown in Figure 1.

Integration of IoT for Real-time Monitoring At the core of MANTRA's functionality is the integration of IoT technology. By harnessing the power of a network of sensors and interconnected devices, MANTRA facilitates real-time monitoring of the construction site. This setup enables the immediate detection of changes in the environment that may give rise to new hazards. The real-time data provided by IoT devices ensures that information about temporary danger zones is current, accurate, and instantly available.

Leveraging BIM for Interactive Visualization MANTRA elevates the use of BIM from a planning and design tool to an active participant in safety management. By integrating BIM models into the application, MANTRA offers detailed 3D visualizations of the construction site, allowing workers to interact with a digital twin of their physical environment. This feature not only enhances the understanding of the site layout but also enables users to pinpoint and visualize the exact locations of potential hazards.

Progressive Web App for Enhanced Accessibility Developed as a PWA, MANTRA is inherently accessible across a wide range of devices and platforms. This approach ensures that the application can be used on any device with a web browser, without the need for downloading a dedicated app. The PWA framework offers the advantage of a seamless, app-like experience combined with the accessibility and ease of a web application, ensuring that all workers, regardless of their device type, can access critical safety information.

Proactive Safety Communication A key innovation of MANTRA is its proactive approach to safety communication. Instead of relying on traditional

reactive methods, the application allows for the immediate marking and broadcasting of danger zones within the BIM model. Workers can receive instant notifications on their mobile devices about emerging hazards, significantly reducing the response time and enhancing the overall safety response.

Empowering Workers with Interactive Features MANTRA empowers workers by giving them the ability to interact directly with the safety management system. Users can report hazards, view updates, and even contribute to the safety monitoring process. This interactive participation fosters a proactive safety culture, where each worker becomes an active stakeholder in maintaining a safe working environment.

In summary, the MANTRA project addresses the pressing need for an advanced, integrated safety management system in construction sites. By combining real-time data from IoT with interactive BIM visualizations in a user-friendly mobile application, MANTRA offers a comprehensive solution to the challenges of temporary danger zones. This approach not only enhances immediate safety responses but also contributes to a long-term culture of safety and awareness in the construction industry.

2 Methodology

2.1 App development

During MANTRA development activities, the approach was centered around creating a tool that was not only technologically advanced but also user-centric and universally accessible. The decision to utilize a PWA framework was pivotal in achieving these goals. This choice allowed us to develop an application that seamlessly operates across different devices and operating systems, effectively addressing the diverse technological landscape of construction site personnel.

The development process of the MANTRA app was guided by a commitment to simplicity and ease of use. Recognizing that our users range from tech-savvy individuals to those less accustomed to digital tools, we prioritized an intuitive user interface by circulating to our end-users a set of screens mockups like the ones shown in Figure 2.

The web-based nature of PWAs played a significant role in this aspect. By allowing access through a web browser without the need for downloading a separate app, we significantly lowered the barrier to entry. This ease of access ensures that every worker, regardless of their level of comfort with technology, can interact with the application.

A critical part of the development was the integration of the app with ASSIST-IoT platform for real-time data transmission and BIM for interactive visualizations. This phase required a synergistic effort between the MANTRA app developers team and ASSIST-IoT partners. The goal was to ensure a smooth and effective synergy of these technologies, allowing for a dynamic representation of the construction site and timely updates on potential hazards.

Fig. 2. MANTRA first mockups

Testing and iterative improvement were integral to MANTRA methodology. The application underwent various phases of testing, starting from basic functionality and user interface to more complex aspects like integration with IoT and BIM. This rigorous testing framework enabled us to gather valuable feedback, which was then incorporated into successive iterations of the app. This process of continuous refinement was essential in creating a robust and reliable tool for construction site safety.

Finally, understanding the ever-evolving nature of construction projects and digital technologies, we designed the MANTRA app with scalability and adaptability in mind. The architecture of the app allows for easy updates and the addition of new functionalities as required, ensuring the tool remains relevant and effective in the dynamic landscape of construction site safety management.

2.2 Technologies

For the development of MANTRA application and its integration in the ASSIST-IoT ecosystem, a strategic blend of PWA technology and ASSIST-IoT enablers was employed, creating a platform that is both technologically sophisticated and highly adaptable to the needs of construction site safety management as it is shown in Figure 3.

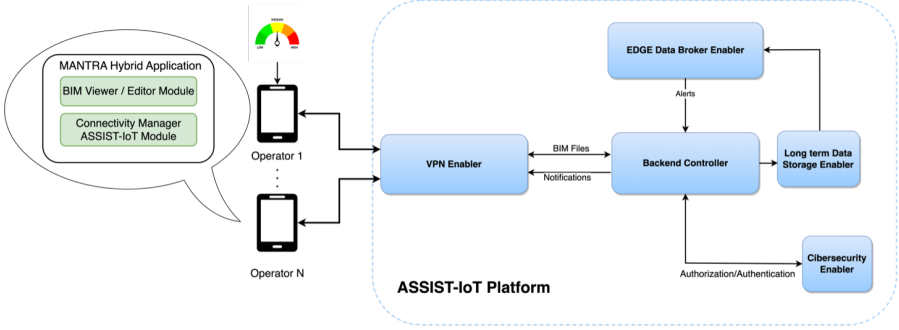

Fig. 3. MANTRA integration with ASSIST-Iot Platform

Progressive Web App Framework The choice to utilize a PWA framework for the MANTRA application was pivotal. This technology allowed us to build a platform that combines the accessibility and ease of a web application with the performance and user experience of a native app. PWAs are inherently cross-platform, enabling the MANTRA application to function seamlessly on any device with a web browser, which is crucial for ensuring that all workers have unrestricted access to the application. The offline capabilities and fast loading times of PWAs also enhance the app's usability in various on-site conditions, where connectivity can be inconsistent.

Semantic Repository Enabler [12] The Semantic Repository Enabler from ASSIST-IoT is integral to the app, enabling intelligent data management and interpretation. This enabler allows the application to effectively process and contextualize the data from IoT devices and BIM models, turning it into actionable insights for hazard identification and management.

VPN Enabler [13] Given the sensitivity of construction site data, security is paramount. The VPN Enabler ensures that all data communication within the MANTRA app is secure, maintaining the confidentiality and integrity of the information transmitted.

Edge Data Broker Enabler [14] This enabler is crucial for the real-time functionality of the app, allowing for prompt data processing and communication. It ensures that the data from the site is processed efficiently, enabling the MANTRA app to deliver timely and accurate notifications about potential dangers.

Cybersecurity Enabler [15] To safeguard against cyber threats, the Cybersecurity Enabler provides additional security layers, protecting not only the data but also the integrity of the app's communication channels.

Long Term Data Storage Enabler [16] This enabler addresses the need for efficient storage and retrieval of historical data, which is essential for risk assessment and the development of long-term safety strategies.

The combination of PWA technology with these ASSIST-IoT enablers results in the MANTRA application being a highly effective tool for safety management in construction sites. The app not only responds to immediate safety needs but also adapts to the evolving demands of construction site environments, ensuring long-term relevance and effectiveness.

3 Results

3.1 App implementation

The implementation of the MANTRA project, involving the deployment of its PWA in construction environments, was a pivotal phase of the project. This phase was marked by strategic integration within a robust technological ecosystem to ensure effective operation in a live setting.

The rollout at construction sites was carefully planned to minimize disruption, with comprehensive orientation sessions demonstrating the PWA's functionalities and ease of access. The web-based nature of the app facilitated its adoption across various devices.

A key aspect of the implementation was the encapsulation of the PWA and its backend within a Docker container [17], deployed on a Kubernetes infrastructure [18]. This approach ensured high availability and scalability of the application, while Kubernetes provided a stable and adaptable environment, facilitating integration with ASSIST-IoT enablers.

The application was integrated with real-time data sources, including IoT sensors and BIM models, essential for real-time monitoring and processing of site conditions and hazards. User engagement and the app's effectiveness were monitored closely, with feedback collected to identify enhancement areas and ensure the app met user needs.

Continuous performance monitoring and technical support were provided throughout this phase, crucial in fostering user confidence and integrating the app into daily site safety practices. The data analysis conducted offered insights into identified hazards and user responsiveness, informing ongoing safety management strategies.

The successful implementation of MANTRA in a real-world construction setting demonstrated its utility in enhancing digital safety management, setting the stage for its ongoing development and refinement.

3.2 Tests and validation

The MANTRA project's phase of testing and validation was a crucial part of our efforts, undertaken within the challenging and dynamic environment of the Marshal's Office construction site in Szczecin, Poland. Specifically, the application

was evaluated under the ambit of Business Scenario P2-3: Safe Navigation, part of the Smart Safety of Workers Pilot. This scenario offered an ideal opportunity to test the app's capabilities in real-time navigation and emergency response in a complex construction setting as it is shown in Figure 4.

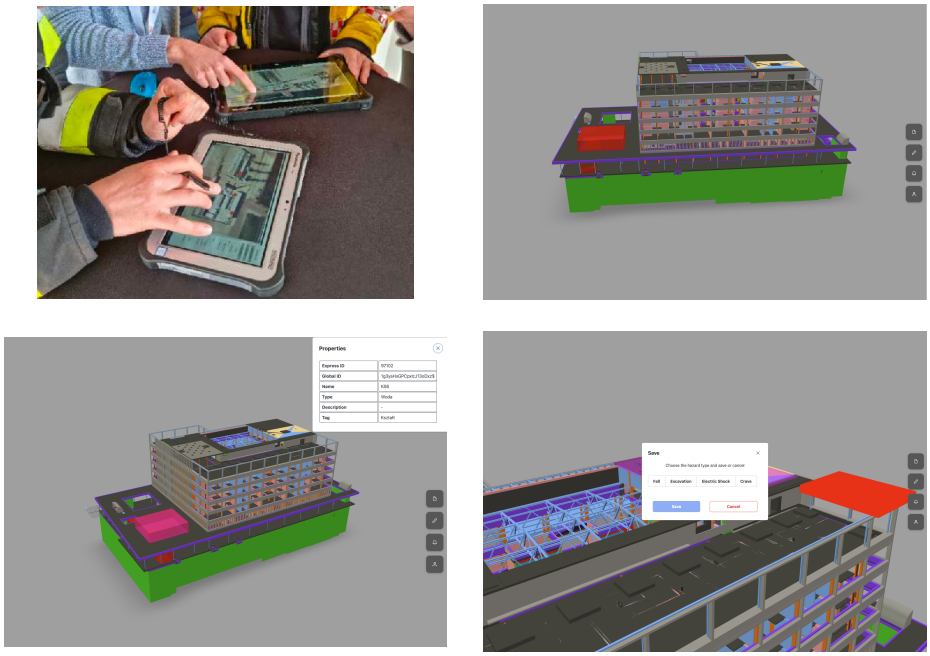

Fig. 4. MANTRA Scenario Demonstration

In implementing the Safe Navigation scenario, the primary objective was to assess MANTRA's effectiveness in guiding construction workers during emergency evacuations. The application, leveraging its integration with IoT and BIM technologies, provided real-time, updated evacuation routes tailored to the constantly changing landscape of the construction site. This feature was particularly significant given the unpredictability of the site conditions, where safety hazards could emerge rapidly due to various factors, including weather changes, ongoing construction activities, and the movement of heavy machinery.

The real-world testing environment of the Marshal's Office site presented a comprehensive range of challenges typical to construction settings. It was crucial for MANTRA to demonstrate its adaptability and accuracy in this dynamic environment. Simulated emergency drills were conducted to evaluate how effectively the application could guide workers to safety, considering both the evolving physical layout of the site and the environmental factors monitored through IoT sensors.

Table 1. User Feedback and Satisfaction Ratings for MANTRA App

User Role	**Feedback**	**Rating)**
Site Manager	MANTRA significantly improved our safety response times.	5/5
Construction Worker	The navigation and hazard alerts are very helpful.	4.5/5
Safety Officer	This app has made monitoring site safety more efficient.	4.8/5
Project Supervisor	The integration of real-time data has been a key point.	4.7/5

User feedback was an integral component of the validation process at it is reflected in Table 1. The insights gathered from the construction workers and site safety managers were invaluable in assessing the app's usability and its impact on enhancing safety practices on the site. Their experiences and suggestions contributed significantly to iterative improvements, ensuring the application was finely tuned to meet the needs of its end-users effectively.

Additionally, data analysis played a vital role in understanding the application's performance during emergency scenarios. By examining response times, evacuation routes taken by workers, and overall adherence to safety protocols, we were able to gauge the efficiency of MANTRA's navigation guidance. This analysis not only validated the app's functionality in a live setting but also provided essential learnings for future enhancements.

Through this validation process in the Safe Navigation scenario, the MANTRA application proved its potential as a transformative tool in construction safety management. It demonstrated a significant capacity to enhance worker safety by providing informed, real-time navigation solutions, thereby validating the practical application and efficacy of integrating IoT and BIM technologies in managing the complexities of construction site environments.

4 Conclusions and Future Directions

4.1 Conclusions

The MANTRA project has significantly advanced the field of construction safety management. Integrating a Progressive Web App (PWA) with IoT and BIM technologies, the project has successfully tackled the challenge of real-time hazard identification and navigation in dynamic construction environments. The positive feedback from users and the effective implementation of the app underscore its potential to markedly improve safety response times and situational awareness.

Key achievements of the project include:

– Successful deployment of the PWA in a real-world construction environment, demonstrating its practicality and effectiveness.

- Effective integration with IoT sensors and BIM models, enabling real-time data access and site visualizations.
- Positive reception and feedback from users, highlighting improved safety management and operational efficiency.

4.2 Future Directions

Building upon the success of the MANTRA project, the following future directions are proposed:

1. **Enhanced Data Analytics:** Utilizing advanced data analytics and machine learning to predict potential hazards, transitioning from reactive to proactive safety management.
2. **Augmented Reality Integration:** Incorporating AR features for more immersive user experiences, further improving navigation and hazard identification.
3. **Expansion to Other Industries:** Adapting the MANTRA framework for use in industries with similar safety challenges, like mining or manufacturing.
4. **User Experience Optimization:** Continuously refining the app based on user feedback to enhance usability and engagement.
5. **Scalability and Interoperability:** Focusing on scalability for larger projects and enhancing interoperability with other construction industry tools and platforms.

In conclusion, the MANTRA project represents a significant step forward in the use of digital technologies for construction safety. Its future development promises not only to further enhance workplace safety but also to lead the way for smarter, technology-driven practices in the construction industry and beyond.

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