



ULTRAWIDEBAND SENSOR DATA INTEGRATION TO BIM ENVIRONMENT USING REVIT API

Esma Rezan Karaca, Semra Çomu Yapıcı, and Umutcan Kılıç
Bogazici University, Istanbul, Türkiye

Abstract

This study establishes a framework for integrating Ultra-wideband (UWB) sensor data into Building Information Modelling (BIM) systems using Autodesk Revit API (Application Programme Interface) for real-time visualization and tracking of workers. The constructed system enables dynamic monitoring of worker positions in a BIM platform, by leveraging UWB technology and Revit's extensibility to construct a digital twin environment for construction site evaluations. The research methodology encompasses sensor data acquisition, real-time visualization, and coordinate transformation for accurate tracking. The system was experimentally tested in a controlled environment. The gathered data incorporated into a BIM model demonstrates enhanced tracking accuracy.

Introduction

Construction sites are inherently dynamic environments, characterized by significant challenges in safety management, operational efficiency, and real-time situational awareness. Traditional safety monitoring methods in construction commonly rely on manual inspections and static surveillance systems, which are often inefficient, error-prone, and inadequate for timely interventions (Cheng et al., 2013). Delays in identifying hazardous conditions or coordinating resources such as labor, machinery, materials frequently result in increased risks of accidents and reduced productivity. In response, the construction industry has progressively adopted digital twin technologies advanced virtual models synchronized in real-time with physical environments to enhance site management, improve risk assessment, and support informed decision-making processes (Park et al., 2023; Deng et al., 2021). Digital twin systems have transformed the way construction projects are managed by enabling real-time risk detection, precise movement tracking, and enhanced instant awareness. Real-time location sensing (RTLS) plays a critical role for context-aware safety management and resource coordination (Cai et al., 2020). Accurate real-time tracking of workers' locations enables site managers to mitigate safety risks, respond promptly to incidents, and streamline

workflows, which ultimately enhances overall productivity.

Researchers have long recognized that real-time location awareness of construction resources would be highly beneficial. For example, making live location data available can assist in timely decision-making and provide greater control over site processes, ultimately improving both productivity and safety (Park et al., 2016). In this sense, Ultra-Wideband (UWB) technology has emerged as particularly advantageous for real-time tracking applications, providing highly accurate localization with sub-decimeter precision, essential for managing worker safety and operational effectiveness in complex indoor environments (Lou et al., 2022; Teizer et al., 2008). This research aims to integrate UWB sensor data with Building Information Modeling (BIM) platforms, specifically leveraging Autodesk Revit's API for visualization and data management. By facilitating the real-time tracking of workers through BIM, the study seeks to address existing technical challenges related to the integration and visualization of dynamic construction data. This integration provides construction managers with timely, actionable insights, thereby improving site management and enhancing worker safety.

The widespread adoption of BIM in construction, using visual scripting interfaces such as Revit API and Dynamo plug-in significantly simplifies data integration, reducing complexity and enabling efficient management of dynamically acquired sensor data (Kensek, 2014). Despite the advances, leveraging UWB-BIM integration remains challenging. However, integrating UWB technology with BIM represents several challenges. Studies have reported issues including data interoperability problems, limited update rates, and decreased accuracy in complex indoor environments (Fang et al., 2016; Park et al., 2016; Deng et al., 2021). In most cases, the integration between UWB systems and BIM was custom-built and not generalized, which highlights a need for a more unified approach (Fang et al., 2016; Park et al., 2016). The research presented in this paper addresses this gap by proposing a novel framework that integrates UWB dynamic positioning data with BIM in real-time utilizing Revit API through plugins. In contrast to previous studies, the proposed system is

designed to be scalable and generalizable, allowing live UWB tracking of multiple resources to directly update their positions inside a BIM model without manual intervention.

Background

Real-time location tracking has been a subject of significant research in the construction sector due to its potential to improve safety, resource management, and overall productivity. Despite extensive theoretical exploration, practical application in indoor construction environments remains limited, largely because of technological limitations and implementation challenges (Park et al., 2016). Traditional tracking technologies such as RFID, GPS, and AI-based vision have shown substantial limitations indoors, including issues related to signal interference, occlusion, and operational costs (Hou et al., 2021). In contrast, UWB technology excels in challenging indoor environments due to its broad frequency spectrum and robustness against multipath interference, thus making it highly suitable for precise real-time localization on construction sites (Lou et al., 2022; Young et al., 2021). Nevertheless, integrating real-time sensor data with digital BIM models, such as Autodesk Revit, remains challenging due to the complexity of accurately aligning physical sensor coordinates with digital model geometries. Robust algorithms for coordinate transformation and optimization of sensor placement have been proposed as effective strategies to mitigate these integration issues (Lou et al., 2022; Hu et al., 2024). BIM provides a centralized platform for effectively managing and visualizing comprehensive construction site data, enabling improved spatial awareness and advanced risk assessments essential for proactive safety management (Desogus et al., 2021; Zhang et al., 2015).

Real-time integration of external sensor data into BIM significantly enhances its capacity for dynamic risk

assessments and responsive safety interventions, fostering safer working environments and more informed decision-making processes (Zaman et al., 2024).

Moreover, representing workers in BIM as dynamic, parametric components offers substantial benefits for tracking detailed activities and behaviors, facilitating real-time visualization, behavioral analytics, and enhanced safety monitoring (Kensek, 2014). Integrating real-time UWB tracking within BIM-based digital twins is therefore pivotal for reducing construction delays, effectively managing dynamic site conditions, and proactively mitigating safety hazards through precise, spatially accurate worker location data (Umer et al., 2020; Rodriguez, 2010). The practical simplicity of deploying UWB sensors combined with accessible scripting platforms like pyRevit or Dynamo ensures this methodology’s feasibility and adaptability across various construction industry contexts.

Comparison of Tracking Technologies for BIM Integration

Table 1 provides a comparative overview of the most common RTLS solutions, including UWB, RFID, GPS, vision-based tracking, and BLE, based on key performance criteria relevant to a construction context (Cheng et al., 2013; Shamsollahi et al., 2024; Lou et al., 2022; Pereira et al., 2024). These criteria include positioning accuracy in indoor environments, cost implications, scalability to large sites or crews, tolerance to occlusion (signal blockage or line-of-sight issues), capability for real-time updates, compatibility with BIM software programs, and ease of deployment on construction sites. Although system requires a higher setup effort and cost compared to other alternatives with ranging errors as low as a few centimeters UWB stands out as the most precise and reliable solution for real-time indoor tracking, which is essential for an effective construction digital twin. In scenarios where accuracy is crucial, capabilities of UWB justify its complexity.

Table 1: Comparative Analysis of Worker Tracking Technologies)

Technology	Indoor Precision	Relative Cost	Deployment Flexibility	Resilience to Obstruction	Live Data Streaming	BIM Integration Potential	Setup Simplicity
UWB	Highly accurate to within centimeters	Affordable	Expands moderately well across zones	Performs well even with obstacles	Excellent for continuous tracking	Usable with 3D BIM with free plugins	Requires sensor calibration (Lou et al., 2022; Cheng et al., 2013)
RFID	Basic to moderate depending on tag type	Very cost-effective	Handles large-scale use easily	May suffer in cluttered zones	Captures presence rather than live movement	Works for basic 2D zone mapping	Straightforward to install (Pereira et al., 2024)
GPS	Poor for interiors	Affordable to moderately priced	Highly scalable outdoors	Signals easily blocked by structures	Supports regular position updates	Limited due to poor indoor function	Simple outside, unreliable inside (Shamsollahi et al., 2024)
AI Vision	Moderately reliable depending on calibration	Mid-range expense	Moderately extensible	Struggles without direct view	Provides frequent detections	Adaptable with model calibration	Medium complexity (Shamsollahi et al., 2024)
BLE	Accurate within 1-2 meters	Low-cost hardware	Scales well in coverage	Moderate resilience to signal blockage	Reasonable update rate	Integrates with some tuning	Quick and simple to deploy (Lou et al., 2022)

Methodology

System Architecture

This study presents a novel framework that enables real-time tracking and visualization of construction worker locations within a BIM environment. The architecture integrates Ultra-Wideband (UWB) sensor data with Autodesk Revit through the Revit API, enabling dynamic monitoring of worker movements. The system architecture comprises four main components: sensor data collection, coordinate transformation, BIM model development, and Revit API-based integration. This ensures the scalability and adaptability of the system for varying construction settings. **Figure 1** illustrates the architectural workflow of the framework that enables real-time updates, allowing site managers to monitor worker movements.

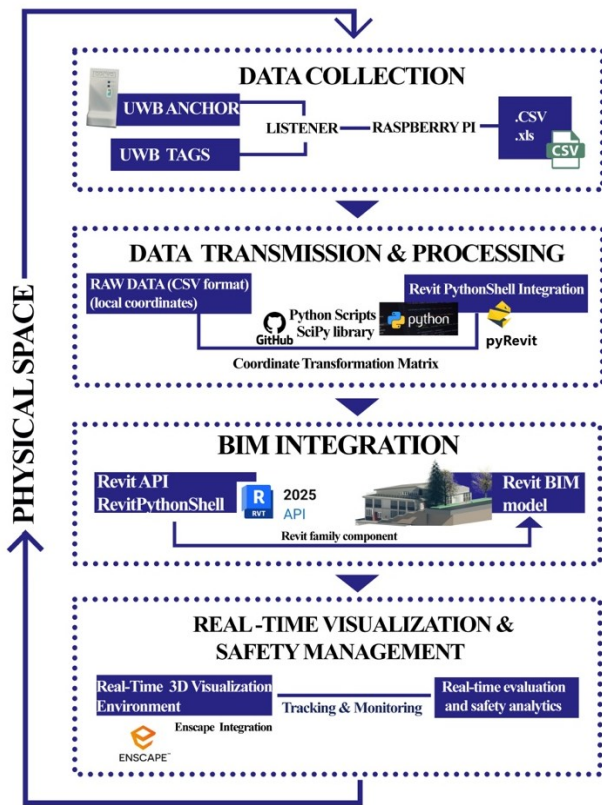


Figure 1: Proposed Framework Integrating UWB Location Data into BIM Environment

Sensor Data Collection

UWB technology was employed for its superior sub-meter accuracy and robustness in indoor environments. Sensor data acquisition structured around four primary stages: establishment of a local coordinate system, tag-based mobility, real-time data logging and structuring, and data output enabling accurate and scalable worker tracking. Anchors were arranged in a configuration to establish a local coordinate system. UWB anchors are fixed sensors to establish an optimal local coordinate system that maximizes coverage. UWB tags are the sensors carried by the moving humans that enable us to monitor their movements.

Data Transmission & Processing

A critical component of the system was transforming UWB-generated local coordinates into Revit’s global coordinate system. A transformation matrix was derived by selecting three or more non-collinear anchor positions with known coordinates in both systems. Using Python scripts executed via the Revit Python Shell and SciPy, transformation equations (including translation, rotation, and scaling) were applied to align sensor data within the BIM geometry. The resulting matrix ensured accurate spatial registration between the physical site and its digital twin representation. Equation (1) defines this transformation:

$$P_{Revit} = T \cdot P_{UWB} \quad (1)$$

where P_{Revit} is the BIM coordinate, P_{UWB} is the sensor coordinate, and T is the transformation matrix.

BIM Integration via Revit API

High granularity was essential for accurate mapping of sensor data and for simulation of worker tracking. The BIM environment served as a digital twin, supporting risk analysis and real-time activity monitoring. This level of detail allows for accurate visualization of worker movements and supports multi-disciplinary coordination within a construction ready digital twin environment. To ensure precise mapping of UWB sensor data to real-world positions, the accuracy of the 3D BIM model was critical. We implemented a structured workflow using Revit Python Shell and pyRevit to integrate UWB sensor data into Revit’s BIM environment effectively. The process begins with pyRevit, an open-source extension that enhances scripting capabilities within Revit, enabling real-time updates on worker positions. Once pyRevit is configured, the Revit Python Shell is used to execute Python scripts, facilitating the seamless integration of location data from UWB sensors. The workflow starts with loading UWB sensor data stored in CSV format, which contains timestamped X, Y, and Z coordinates. These raw coordinates will be transformed from their local reference system to global coordinate system of Revit, ensuring precise spatial alignment with the BIM model.

Real-Time Visualization with Enscape

Enscape is a real-time rendering and virtual reality plugin that integrates with BIM software such as Revit. In the construction industry, real-time visualization tools like Enscape have been employed to plan and execute projects. For instance, Turner Construction has utilized Enscape to visualize, plan, and execute projects demonstrating the capability to integrate with project workflows effectively of the plugin (Pinheiro, 2021). Once the UWB-driven movement of the worker family runs, Enscape will be activated to observe the scene. Visualization from the software can be viewed on a monitor or even through VR headsets via Enscape, offering an interactive way for project managers or safety officers to monitor worker positions within the virtual building. The use of widely available software proves the practicality of the approach that no specialized or

expensive custom visualization platform or specialized skill was needed, since the BIM environment itself became the interface for real-time tracking.

Experimental Setup

Experimental testing in a controlled environment demonstrates the effectiveness of the system in improving tracking accuracy and construction site management. For this purpose, Qorvo DWM1001 model UWB sensors were used in the experiment. UWB anchors were located in a rectangular configuration on the opposite walls of the building. **Figure 2** shows the locations of anchors in the relative XYZ coordinate system and the general architecture of the experiment environment. In the experiment, the walking paths for the subjects were predetermined. Each of the six subjects followed the same two paths, walking along the X-axis and Y-axis in two different directions. This structured movement enabled a controlled study of UWB sensor accuracy, allowing for precise tracking and analysis of worker movement patterns. Construction workers were represented in the experiment by students. The movement of the subjects' bodies were the most important data for this investigation.

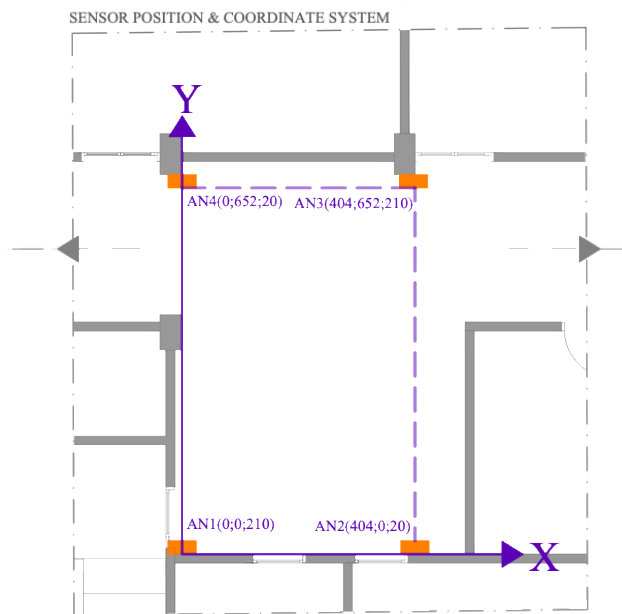


Figure 2: Anchor Orientation and Relative Coordinate System

For this reason, UWB tags were attached to various portions of the subjects' bodies in order to collect data on their movements. Each student was provided with four pairs of UWB tags, which were placed in multiple points on the following locations: below the knees, around the waist, around the shoulders, and around the head. **Figure 3** shows the UWB tag placements on participants. For the purpose of correctly observing the movement of various body parts, each pair of tags was positioned at the same level. And the listener collected positional raw data at fixed intervals. The obtained positional data from sensors per subject were averaged to determine a central reference point representing the subject's center of mass. Subjects were observed walking predefined paths along X and Y axes with a deviation of sub-decimeter from the

experimental path, confirming the spatial accuracy of the system. The processed data is stored in formats like CSV or .XLS for further use.

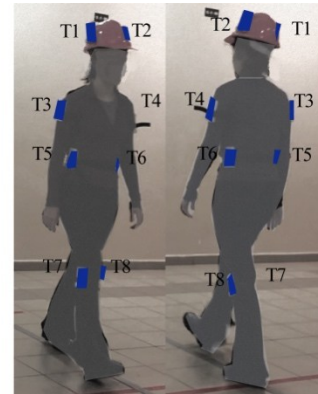


Figure 3: Non-Fixed Tag Placement on The Subject

A 3D BIM model of the experimental site in a university corridor measuring 6.6 m by 4.2 m was developed at LOD 400 using as-built CAD drawings to ensure dimensional fidelity. 3D BIM model generated in Revit according to LOD 400 using as-built CAD drawings, ensuring an accurate spatial representation of the experiment site. **Figure 4** displays a screenshot of the BIM model generated in Revit.

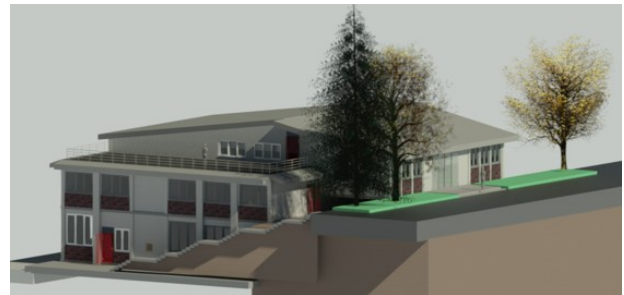


Figure 4: Revit Model of the Experiment Building

To enable real-time visualization, Revit API Integration was developed, utilizing Python scripts to process and visualize worker positions dynamically. Data from the data movements in two different directions were integrated simultaneously to test whether the assigned components were correctly oriented in the appropriate direction when placed on the different axes. Also to ensure the tracking of multiple workers time frame of the obtained location data modified of different subject integrated in to the system by pyRevit. The Spyder environment was used to prepare scripts, which were then executed in Revit's interactive Python shell via the pyRevit plugin. Additionally, Revit API docs were used for developing scripts written for family component assignments. To correct discrepancies between real-world sensor positions and the virtual model, a transformation matrix was applied. The Revit Python Shell played a crucial role to enable real-time execution and modification of scripts without requiring extensive software recompilation. This capability allowed for interactive debugging. Visual studio and GitHub were also utilized in the enhancement of the written scripts in the interactive Revit PythonShell. We used visual studio to enhance PyRevit script efficiently. Integrating PyRevit

with Visual Studio allows to write, test, and debug the scripts in real-time, making the development process smoother.

For enhanced visualization, Revit Family Components were used to represent worker movements. Each worker was assigned a predefined human figure component, and movements were implemented by mapping timestamped UWB data to these components within the BIM model. **Figure 5** demonstrates the family component that is used to create human figure in the Revit model. The Revit API provides methods to move elements or to directly assign their location. In our case, because the movement was frequent and incremental, we used the `ElementTransformUtils.MoveElement()` function on the family instance and directly modified its `Location.Point` property, passing in the translation vector from the old position to new position.

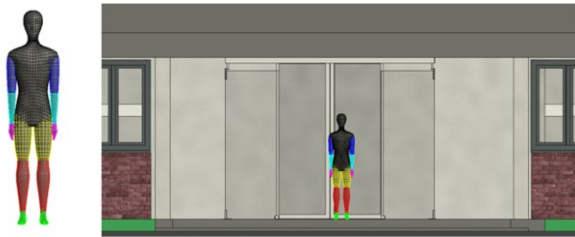


Figure 5: Revit Family used for Human Figure

As the final step to test accuracy, we compared the recorded positions of the assigned family components with actual tracked worker locations.

Findings and Discussion

UWB sensors operate in a local coordinate system, whereas Revit uses a global coordinate system. Aligning these two requires a transformation matrix computed using SciPy/NumPy. Despite Revit API constraints, the developed framework effectively incorporated real-time worker mobility data into BIM, demonstrating its usefulness in various areas including safety management. Before running the Revit script, the average X and Y coordinates obtained from eight different tags were calculated for each object, while the Z coordinate was fixed at foot level. The purpose of this was to prioritize accurate positioning in the Revit model environment rather than focusing on human minimal movement that body makes. The generated family component operates at a specific Z level, ensuring the more consistent visualization. In the Revit environment levels are used as the primary reference levels instead of Z axis coordinates. The X and Y coordinates were determined by placing the selected anchor points within the specified rooms ensuring the proper spatial alignment in the model with the constructed relative coordinate system in the experiment.

The visualized location data was verified using Enscape plugin which allows to monitor 3D visualization modified as a tool for live updates in the Revit model in the virtual environment. The main reason choosing the Enscape plugin is its compatibility with Revit and its interface, which allows tracking the BIM information of the model

using the BIM command. While specific academic research detailing the use of Enscape for real-time location are limited, industry case studies and practical applications justifies its effectiveness within the Revit environment (Chaos, 2024). **Figure 6** demonstrates the visualization of the script that assigns a family component via pyRevit in Enscape plugin at specific time intervals to the location data collected.

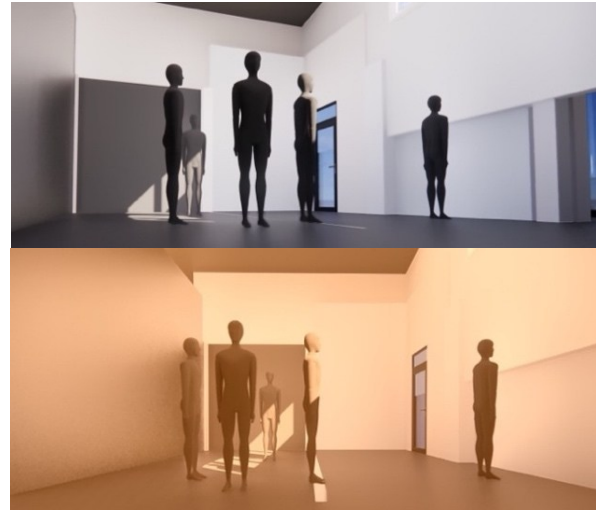


Figure 6: Revit Enscape Monitoring Integrated components into the 3D model

As the Python script updated the worker's position in Revit, one could see the *worker avatar moving along the floor plan in Enscape* essentially creating a live animation driven by the UWB data. We ensured that the family representing the worker was visually distinctive. Enscape was started and pointed to the active Revit view that included the worker family. Because Enscape syncs with the Revit model in real-time, any movement or change to elements in Revit is reflected almost instantaneously in the Enscape window. **Figure 7** illustrates the Revit model interface while the script is running using the Revit PythonShell assigns the specific component that is highlighted. The system demonstrated sub-decimeter accuracy (less than 10 cm) in tracking worker movements, with minimal deviation between recorded and actual positions. Components placed in the correct environment around the reference line within a 10 cm tolerance maximum. Real-time visualization aimed to improve site monitoring, reducing the need for manual tracking methods.

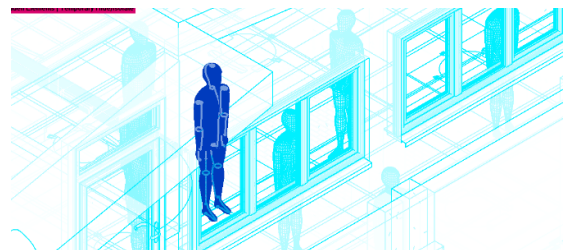


Figure 7: Revit Model Run Script

The integration of UWB data into Revit BIM allowed for enhanced visualization and risk assessment in construction management. A tracking line of the subject

movement on the Revit model plan is represented in the **Figure 8**. This location mapping may cover further health and safety risk analysis.

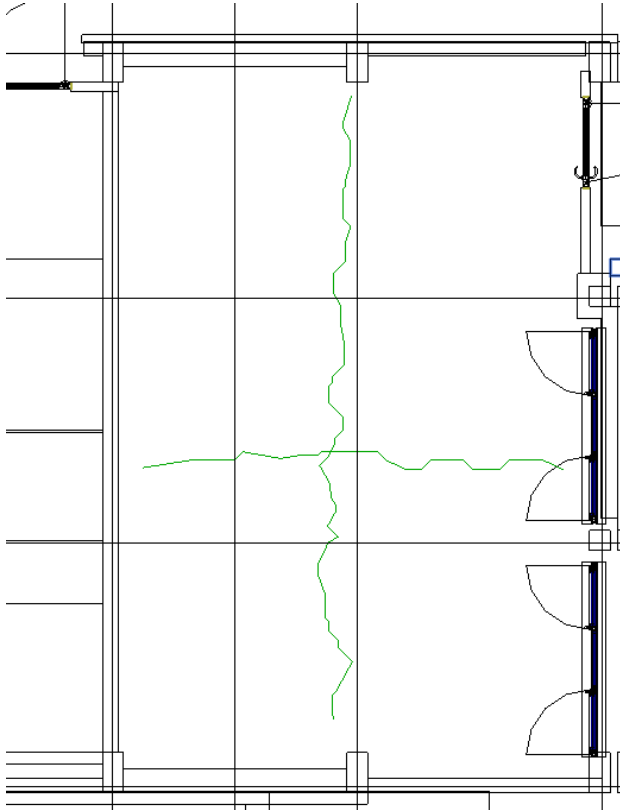


Figure 8: Movement Track Line

The pyRevit plugin leveraged Revit API for seamless visualization, while Enscape plugin was used to enhance the real time representation of the collected data. In short, Revit can dynamically display the workers movement path. In this study, the time intervals for assigned location points in the pyRevit script were set to 3 seconds, while the command for deleting previously assigned family components was set to 10 seconds. This configuration allowed for observing the movement direction while enabling the simultaneous visualization of multiple family components at different points. The main purpose of assigning the components at specific time intervals is to only update positions if they change significantly. Similar methods have been employed in related studies. For instance, Meoni et al. developed a Python based software application named H2BIM, which integrates sensor data into the Revit environment to monitor structural performance. Their approach involved processing sensor data at specific intervals to maintain meaningful visualizations without overloading the system. In scenarios where workers moved along a specific axis with millisecond differences, such as negligible changes were not perceptible in the Revit model.

In the experiment, when walking along a specific axis with millisecond differences is not noticeable change that could be observed in Revit model and the Revit software struggled to assign components to nearby positions less than 10 cm accurately. Also, Revit is not optimized

software for sub-centimeter calculations which limitates small scales (Autodesk, 2021).

The proposed framework enhances visualization in a digital twin environment by improving construction site management and facilitating real-time worker position identification for increasing safety. Additionally, the system supports enhanced decision-making by also enabling work in a BIM-integrated environment. Since we can track workers in BIM, we could also overlay safety related data or triggers for risk alerts. For instance, we can define hazard zones or prohibited areas in the BIM as 3D volumes or marked areas to enhance worker safety (Kulinan et al., 2024; Tran et al., 2023). The dynamic worker components could be programmed to change appearance such as turning red or prompt an alert when entering these zones, effectively creating a real-time geofencing system for safety. The concept geofencing which refers to the creation of virtual boundaries in a physical space using location-based technologies has been demonstrated by Nachiappan et al. (2024) alerts and enforce location specific controls by enhancing worker protection. Additionally, the movement data could be analyzed to detect anomalies, if a worker falls or remains motionless for an unusual period, the system might infer a potential injury, automatically alerting it in the BIM model by coloring the worker's component or sending a notification with connecting both with Revit and server. Because Revit allows scheduling and attaching parameters to the elements, we could log each worker's path and time in certain locations, contributing to safety audits such as how long was a worker in a high-risk zone, were they exposed to a hazard longer than allowed, etc. Furthermore, the BIM environment could serve as a command center for safety management. To use this framework for real-time research that requires additional location data from several points at the same time, database storage should be set up, as well as an API for retrieving UWB data from the cloud and handling and processing large amounts of UWB sensor data. Aligning UWB local coordinate systems with global coordinate system of Revit caused a significant computational challenge. It was challenging to construct an appropriate transformation matrix to align the local coordinate system with the Revit environment, which was necessary to improve the global positioning system's functionality. Several Revit API scripts were generated for optimizing coordinate system. To solve the problem of constructing an appropriate transformation matrix for aligning the local coordinate system with Revit, as well as exploring GPS-based solutions and automated routing, GPS could be used to improve localization enhancing the speed of the real -time integration but it comes with significant limitations indoors. So, merging UWB data and GPS to prevent the coordinate transformation efforts could be an efficient method by utilizing Kalman filtering (Jung et al., 2023).

The case study observed sensor occlusion issues when body parts obstructed the sensor's line of sight during movement. Because sensor occlusion problems happen when body parts get in the way of the sensor's view while

the person is moving, it has been decided that putting data from different parts of the body into the system as a whole is not a beneficial idea for Revit visualization. It was found that combining data from each body part separately and mapping them to different components was a better way to deal with the sensor data points from different body regions that were located to different Revit components than combining all the data at once. This method ensures a more accurate detection of variations in different body regions, resulting in a more realistic representation of movement within the system. Accordingly, one can add obstacle-aware routing to guide workers away from danger zones.

For more accurate solutions, it is recommended to combine GPS (Global Positioning System), UWB, and Inertial Measurement Unit (IMU) sensors using a fusion technique (Zhang et al., 2023). Integrating GPS, UWB, and IMU sensors can significantly enhance real-time localization accuracy in construction environments. GPS provides reliable outdoor positioning, but its accuracy degrades indoors due to signal obstructions. UWB compensates for this limitation by offering precise indoor positioning through high-frequency signal transmission. Meanwhile, IMU sensors measure acceleration and angular velocity, enabling motion tracking (Zhang et al., 2023). A sensor fusion approach leveraging Kalman filtering or deep learning-based sensor fusion algorithms can effectively merge data from these different positioning technologies, ensuring a seamless transition between indoor and outdoor environments (Li et al., 2018).

This integrated system can significantly enhance construction site tracking, improving safety monitoring more accurately with less distance difference. The BIM model becomes more than just a visual tool, it provides a foundation for a smart and responsive system that helps prevent accidents. This transformation is important for dynamic digital twins for construction site safety concerns (Park et al., 2023; Kulinan et al., 2024).

In result, this research suggests to improve the real-time execution of the system, enabling immediate responses, reactions, and proactive hazard prevention based on sensor feedback. Additionally, integrating AI-based navigation into BIM and the Revit API can optimize job site workflows and reduce idle time by adjusting the dynamic worker paths. Similar approaches integrating AI-driven navigation into BIM for dynamic optimization have been investigated in recent studies (Zhang et al., 2022). The implementation of enhanced machine learning algorithms for predictive safety measures could be explored to enhance the adaptability and decision-making capabilities of the system developed.

Conclusion

This research demonstrated the feasibility of integrating UWB sensor data with BIM using the Revit API for real-time worker visualization. The proposed framework significantly enhances safety and efficiency by providing a proactive monitoring tool, but real-time processing challenges require further optimization and research.

Unlike traditional static BIM uses, our system provides a situational tracking tool for construction managers. It allows direct monitoring of the multiple workers simultaneously in a realistic 3D BIM environment, improving spatial understanding and hazard recognition significantly. The framework leverages accessible, widely-adopted industry tools (Revit API, pyRevit, Enscape), emphasizing ease of deployment, scalability, and applicability without the need for specialized software skills or additional high-cost system infrastructure. Future research may focus on scaling the system for larger projects, improving data processing algorithms, and integrating predictive analytics to anticipate hazards proactively. The integration of real-time hazard detection within BIM environments can greatly improve worker safety. The BIM model, enriched with dynamic hazard mapping, can also be used by site managers to monitor worker safety violations in real-time, improving proactive risk mitigation strategies. Overall, the integration of UWB based real-time tracking with BIM contributes to the development of smarter and safer construction sites.

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