Augmented and Virtual (Mixed) Reality for Asset Management in a Construction Warehousing Facility: A Modelling and Simulation Study

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ABSTRACT

This research presented a practically achievable scenario of a smart warehouse receiving smart containers to be inspected smartly and effectively. This research had four objectives: review role of augmented and virtual realities in construction warehousing; define a scenario in an example construction warehousing layout and create modelling and simulation environment in Blender; simulate the scenario in interactive mode and record the features and experiences; and make recommendations for its practical implementation. A 3D model of an example scenario of inspection of containers was created in Blender software, and its Augmented Reality (AR) functionalities were configured for a simulated experience. An example process of inspection of the containers offloaded in a temporary construction warehouse was experienced within the 3D model and key features and experiences were recorded. The simulation helped in inspecting the containers using Mixed Reality. Assuming the inspector could access the AR on a Smart Phone, the containers offloaded and docked for inspection were displayed helping the inspector to quickly search a container, reach it physically via virtual path in the Virtual Reality model, and inspect it by matching details with the asset database. The constraints followed by the observer camera can guide a physical smart vehicle enabling the inspector to be auto-driven to the container. A workflow for readying the inspection scenario was proposed to be followed by the asset manager in the AR application with an expanded scenario to accommodate multiple vehicles routed within the warehouse by assigning dedicated paths with cross roads constraints.

Keywords: construction warehousing, virtual reality, augmented reality, 3D modelling, smart containers

1   Introduction

Augmented Reality (AR) is a step ahead of Virtual Reality (VR) in manufacturing and supply chain applications (Buttner *et al.*, 2017; Westphal & Clara, 2017). VR is used for virtual interactive experience with a computer-generated version of a real object (example, a vehicle or a machine). AR incorporates real-world layout of a facility and its objects in a VR environment such that human operators can interact with real objects through a virtual VR screen. Historically, the design space of AR and VR has evolved over multiple decades. However, their actual realisation required many innovations; especially in networking and data management. Network bandwidth, latencies, data storage space, and cost constraints in the past limited their wide usage in industrial applications. The modern Industry 4.0 innovations combined with cloud technologies and new networking technologies (such as, LTE Advanced and 5G) have evolved new opportunities for using AR and VR in industrial engineering applications. For example, an operator can control forklifts and robots from a control room using a mixed reality system of AR and VR without entering the physical operations area.

In this research, a modelling- and simulation-based experience of mixed reality (AR and VR) for an asset management scenario in a warehouse is presented using Blender software; an open source tool for 3D modelling and game development. This research employed the 2.79b version of the software. The aim and objectives of this research are as presented below:

Aim: To simulate and experience a scenario of Mixed Reality used for asset management in an example warehousing layout modelled in Blender Software and make recommendations for its practical implementation;

Objectives:

(a) To review the operations features possible through AR and VR in warehousing;

(b) To define a scenario in an example warehousing layout and create a modelling and simulation environment in an open source 3D modelling and game engine;

(c) To simulate the scenario in interactive mode and record the features and experiences in the scenario;

(d) To make recommendations for its practical implementation;

2 Literature Review

A VR environment is a 3D model design in an interactive virtual environment comprising objects with physical properties similar to their physical counterparts (Lawson, Salanitri, & Waterfield, 2016). The model is first created using three dimensional meshes of the objects present or planned in the physical environment. Thereafter, game environment properties and controls are configured to program the interactive properties of the objects to make them respond to interactive controls conducted through peripherals such as joysticks or other commercially available game controls. The game environment properties are configured with the help of solver equations providing representations of physical properties. For example, if the weight of a car is 2000 Kg, a solver equation makes it behave like a 2000 Kg object standing on a solid surface. Further, solver equations are assigned to make the virtual car interact with road conditions as is expected in an equivalent physical car of 2000Kg weight. The environment around the objects is simulated with the help of environment solver equations; such as, for generating winds opposing the car, and for simulating effects of gravity.

VR also incorporates audio of the objects in action. Headphones or surround sound systems can be used to simulate the audio generated by the objects while they are in operation (Berg & Vance, 2017). For example, the noise generated by a car can be experienced during a virtual test ride on a virtual road in a VR gaming environment. Similarly, noise generated while driving a crane can be simulated in a surround sound system having speakers placed in a VR room. A chair with springs can be used to generate the vibrations and shocks using data collected from the physics solvers in the VR simulation. Interaction with the virtual environment can be done through a 2D or 3D monitor screen, a head mounted immersive display, or 3D holographic projection. Multiple physics solvers in the system interact mutually to generate the physical effects possible within the equivalent real environment. The data used to configure the physics solvers is obtained either from the design documentation or from physics data collected using a variety of sensors in the real environment, such as optical, inertial, magnetic, and ultrasonic sensors). There are gesture and tracking algorithms for simulating the natural movements. Users can navigate through them and control them using game controllers or customised physical controllers.
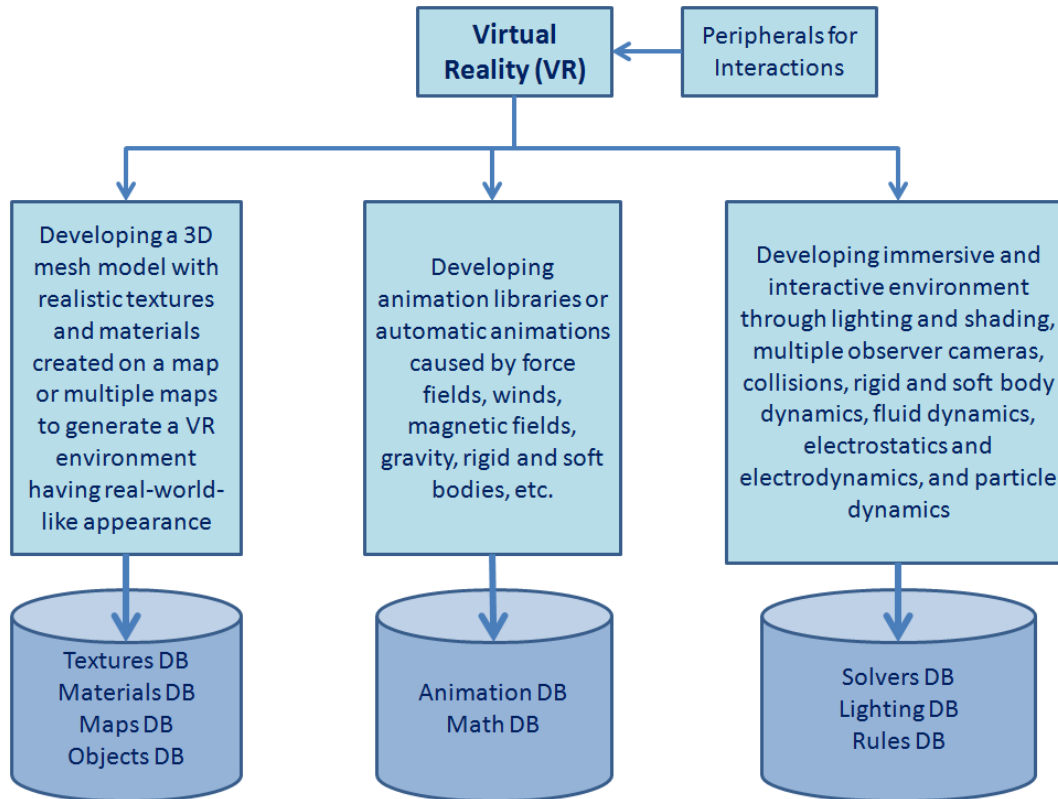
Figure 1: Virtual Reality Designing

Figure 1 presents a schematic of VR designing. This figure is a combined representation of the concepts presented by Flavell (2010), Hilbert & Konig (2016) and Dhalmahapatra *et al.* (2018). The pictorial representation comprising the three major stages and the supporting databases is conceptualised by the author of this research paper based on the concepts by the two cited papers.

The first block in Figure 1 shows the first stage engaged in development of 3D mesh model with textures and materials. In this stage, a large and comprehensive mesh should be created of the facility to be managed. Thereafter, a large number of individual meshes representing machineries, equipment, robots, containers of different sizes, packages of different sizes, vehicles, etc. should be modelled as individual assets. This stage is supported by materials, textures, and maps databases.

The second block in Figure 1 shows the second stage engaged in development of animations or maths for automatic animations caused by dynamic solvers in the software. The solvers include rigid and soft body solvers, winds, tornadoes, and hurricanes solvers, force fields, magnetic fields, and gravity solvers. This stage is supported by animation and maths databases.

The third block in Figure 1 shows the third stage engaged in development of immersive and interactive environment. The interactive environment is created by developing lighting and shading, multiple cameras programmed as observers, assigning all the dynamic solvers to the assets in the model, and defining rules of interactions. This stage is supported by solvers DB, lighting DB, and rules DB.

Now, a major limitation of VR needs to be recognised. It is isolated from the physical environment that it represents. To solve this limitation, AR is the answer (Mainzer, 2017; Gomes, Magaia, & Neves, 2020). VR is a one-time setting created for interactive experience, which may be updated periodically. The databases are created one-time and then updated as minor changes occur in the physical environment that the VR represents.

However, AR works with dynamic databases. The databases shown in Figure 1 are dynamic databases in AR getting data streamed from multiple tracking technologies, such as optical sensors, wireless sensors, RFIDs, GPS, micro- and nano-electromechanical sensors, and Industrial Internet of Things (IIoT) attached to cyber-physical systems. The physical states, 3D position, and 3D orientations of movable physical objects are transmitted continuously to objects database, which are referenced with the maps database to show them dynamically in the 3D view (Segovia *et al.*, 2015; De Pace *et al.*, 2019). The 3D viewport changes continuously using the continuous data feeds. Modern hardware with advanced graphics accelerators ensure real time rendered updating of the 3D viewport. The physical parameters sensed by IIoT-enabled sensors can be streamed into the math and solvers databases to generate real-time changes in animations indicating their operational behaviours.

The data streams from real assets and their real time state updates in an AR application have significant applications in industrial engineering for running operations and maintenance processes (De Pace *et al.*, 2019). For example, the equipment needing maintenance can be identified in the AR application based on the data streams coming from its operational parts indicating problems (such as, extra noise and vibrations beyond set limits). Similarly, AR can also be used as a tool for continuous monitoring of production and quality parameter by sensing the right variables and streaming them into the math and solver databases generating real-time physical behaviours in the 3D view (Segovia *et al.*, 2015).

In industrial engineering, AR can be used for product engineering, process engineering, as well as maintenance and operations engineering in a smart factory setting (Elia, Gnoni, & Lanzilotto, 2016; Rejeb, 2019). Immersive product designs can be used for global collaboration of designers while the actual product may be placed in one location. AR in process engineering can be used to visualise process variables using continuous data streams sensed and transmitted by the IIoT devices attached with the processors. For example, heat of a furnace can be visualised by its changing colour in AR. In operations and maintenance, AR can be used to identify and reduce operational errors and identify equipment and machines needing preventive maintenance (a process called predictive maintenance). AR can also sense motion capture data of robots and send motion data in real time to control their movements (Rivera, 2019).

In modern warehouses, operators can use AR for real-time assets tracking, real time quality controls, and real time controls of operations such as receiving, unpacking, dynamic traffic control, storing, and shipping (Cirulis & Ginters, 2013; Merlino & Sproge, 2017; Agha, Venancio, & Barlasakli, 2020). Operators can use handheld or head-mounted displays to visualise data mapped with physical assets to conduct their operational tasks. The physical map of a warehouse location can be mapped accurately with a virtual 3D map such that every point in the physical map can be accurately mapped with a corresponding point in the virtual 3D map (Sun, Wei, & Kaufman, 2016). Automatic vehicles can be used by tying them closely with pre-defined paths and constraints, and making them smart by communicating with each other and negotiating physical movements, such as crash avoidance (Bechtsis *et al.* 2018). Freight containers can have RFID and IIoT attachments such that they can continuously transmit their stored data and location data to AR database servers through wireless access points (Schniederjans, Curado, Khalajhedayati, 2020).

As presented in Section 1, this research presents a mixed reality modelling environment and its simulation to experience a temporary construction warehousing scenario in interactive mode and record the features and experiences. Further, this research presents recommendations on how the scenario can be realised in a real warehouse. The next section presents the methodology adopted.

3   Methodology

In this research, an example construction warehousing environment is modelled and an asset management scenario has been simulated. The open source modelling and game development software Blender 2.79b has been used to develop the model and simulate the interactions. Latest versions of Blender are much more advanced, but 2.79b was selected to manage hardware compatibility with the existing laptop of the researcher. A simple layout of a temporary construction warehouse was made in which, a circular area for unloading the containers as presented in Figure 2. The area is surrounded by cranes for unloading, which are backdrop images in this scenario because their detailed models were not required to meet the research objectives.

The scenario comprises a number of containers unloaded into the area by two imaginary logistics vendors: ABI and MAS. The scenario involves assets inspection by a field warehousing operations employee using AR. The containers are placed in the warehousing location randomly by cranes. The RFIDs installed on the containers have revealed their 3D location data. RFIDs could not be used by the researcher and hence container location data were entered manually in the Blender software. Figure 2 presents a storage area in which, the containers have been unloaded. The cranes shown are backdrop images but the containers are actual 3D boxes with materials, textures, and solid solver data applied.
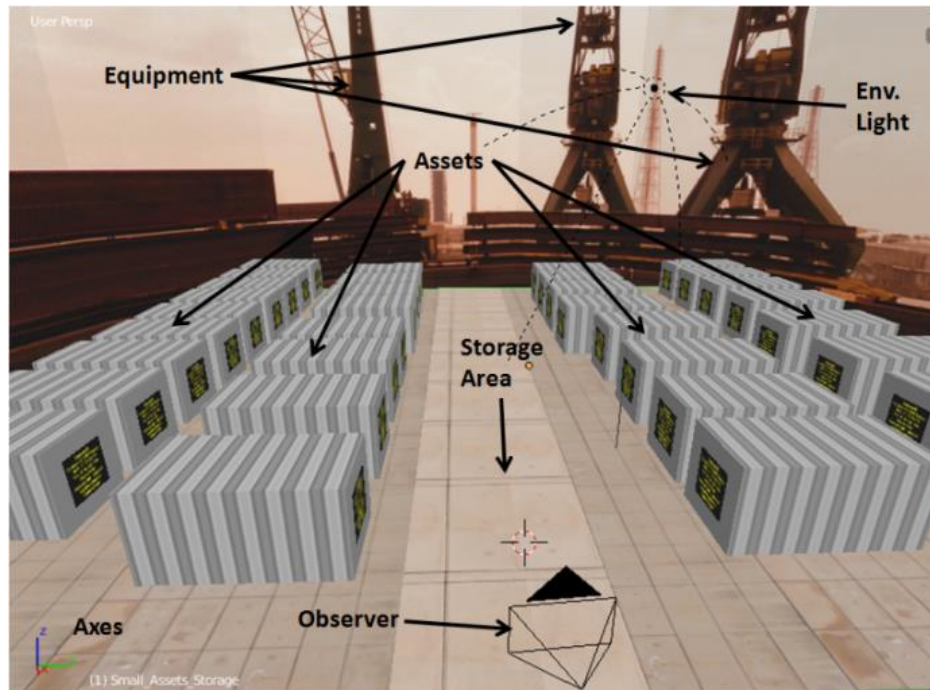

Figure 2: Warehousing scenario modelled in Blender 2.79b

A camera is positioned representing an observer. The view shown in Figure 2 is a perspective view but the actual operations can be simulated by viewing through the camera, which is the observer. The camera is movable and can be rotated only through constraints as shown in Figure 3. Additional constraints can be added by fixing the camera to fixed curves. In a game engine, these constraints are applied to limit the movement of characters and vehicles. In AR, a vehicle can be tied to fixed limits of translation and rotation, and can be constrained to follow a fixed path. The path is a curve following 3D coordinates traversing the physical space. In this model, a curve fitting constraint was not modelled because there is only one observer (on a vehicle). However, curve-based constraints are mandatory when multiple observers/vehicles are modelled.
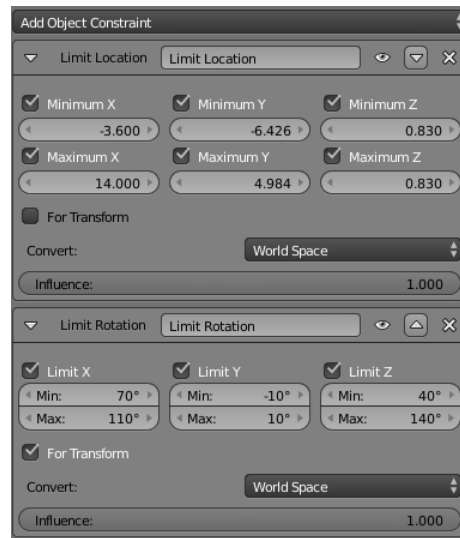
Figure 3: Constraints applied on camera movement

An environment light is positioned to illuminate the entire site. It is a sun that illuminates the entire construction site. Because of hardware limitations, shadows and real time ray tracing were disabled. Now, a simulation of the scenario is explained in the next section.

4   Results

The scenario was simulated by entering the camera view inside observer, as shown in Figure 4. Now, the entire warehouse is visible from the first person's perspective. In a real AR, the camera constraints can be applied to an in-warehouse vehicle to drive it automatically following the path defined. Overlapping of real and virtual coordinates can ensure that the path followed is accurate. The assets delivered in the warehouse are listed in the right pane of the window. The inspector needs to inspect the containers physically following this view. The objective is to visit containers delivered by the two vendors separately. However, they are mixed in the warehouse. To begin the inspection, the inspector needs to first stand at the entry point of the warehouse. This is done by first selecting the observer camera in the right pane, then selecting the menu item object → snap → selection to active.
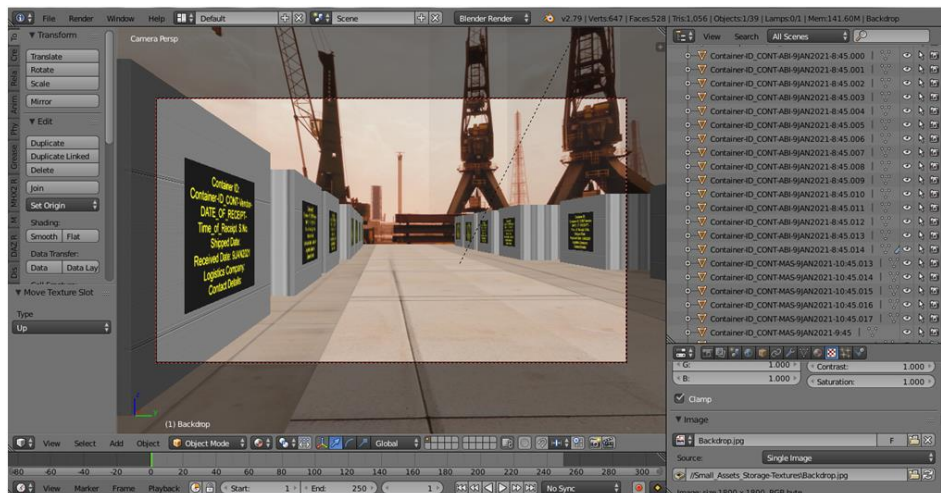

Figure 4: Viewing the temporary construction warehouse through the observer camera with the list of containers displayed on the right hand side

In this window, the observer quickly shifts to the entry of the warehouse (Figure 5). In a real AR scenario, all paths would originate from here and hence it is important for the vehicle to first move to this location. The snap feature can be used for a real world vehicle carrying the observer to identify the source and destination coordinates and the path defined to travel to the destination. In this simulation, the observer camera quickly snaps to the destination coordinates.

Figure 5: Viewing the entry of the temporary construction warehouse through the observer camera

From the entry point, the inspector can now begin inspecting the containers. It may be noted that the entry point is constrained (Figure 3) and hence, the observer/vehicle cannot move backwards. The container ID is displayed in the right pane as shown in Figure 4. The container ID follows the format: Container_ID_CONT-Vendor-Date_of_Receipt-Time_of_Receipt.S.No.

From the ID itself, the inspector can identify the vendor name and the date and time of visit. To reach a particular container, the inspector needs to first select the observer, then select a particular container ID in the right pane, and follow the same menu item. The camera now quickly reaches the face of the container. Two such events were simulated as presented in Figure 6. As the camera movement and rotation are constrained, it will only follow the path to the destination within allowed limits.

Figure 6: Observer camera snapping to the containers selected for inspection

In complex warehouses with numerous observers, the constraints need to be in straight lines only. For example, this temporary warehouse has four rows. If an observer/vehicle is allocated to each row, the constraint window (Figure 3) needs to be configured for each observer allowing movements only on the X-Axis whereas movements on Y and Z axes are blocked. Thus, each vehicle shall move on a straight line for inspecting only the rows to which, they are allocated.

In Figure 6, the two images show the camera getting snapped to two different containers. The large black labels with yellow text shown on the containers are not real. Containers do have the data shown in those black labels but not displayed in this manner. This is another AR feature. The black label in the VR screen confirms that the inspector has reached the right container. The container ID in the right pane of Figure 4 should match the ID displayed on the black label, and also should be displayed somewhere on the physical container that the inspector has reached. This can be achieved using a "dynamic labelling" feature. Label printing from databases is an old technology. In this model, dynamic feature could not be demonstrated. However, in real logistics applications it is very easy to achieve. Instead of printing physical labels, the label printing software can print them into GIF or JPEG images. These images can be dynamically assigned to the black screen portion of the container as a face texture by the asset manager. The full workflow is presented in the next section.

5   Discussion

Figure 7 presents the proposed workflow in the scenario studied. When a container is offloaded and docked, the RFID attached to the container sends its ID, 3D location, received date and time, vendor name, container serial number, and other such details to an asset management database. Ideally, the database should query the RFIDs of all received containers using a beacon. All details retrieved in the database are visible to the asset manager.

The asset manager may follow the workflow of Figure 7 to initiate physical inspection of the containers. There are two steps in this workflow. First, the asset manager imports a container object (a pre-configured 3D mesh) into the VR screen and assign the 3D location data. The container quickly positions itself within the VR at the location where the actual container is placed. Thus, the AR feature of the VR is enabled. Second, the asset manager prints the container data into a label graphics (a GIF or JPEG) file and assigns it to the black screen of the container as a face texture. This entire activity should not take more than a few minutes per container. This is a real time activity as the asset manager will continue this work as the containers are being offloaded. In future, the asset manager can be replaced by AI to complete these two steps.
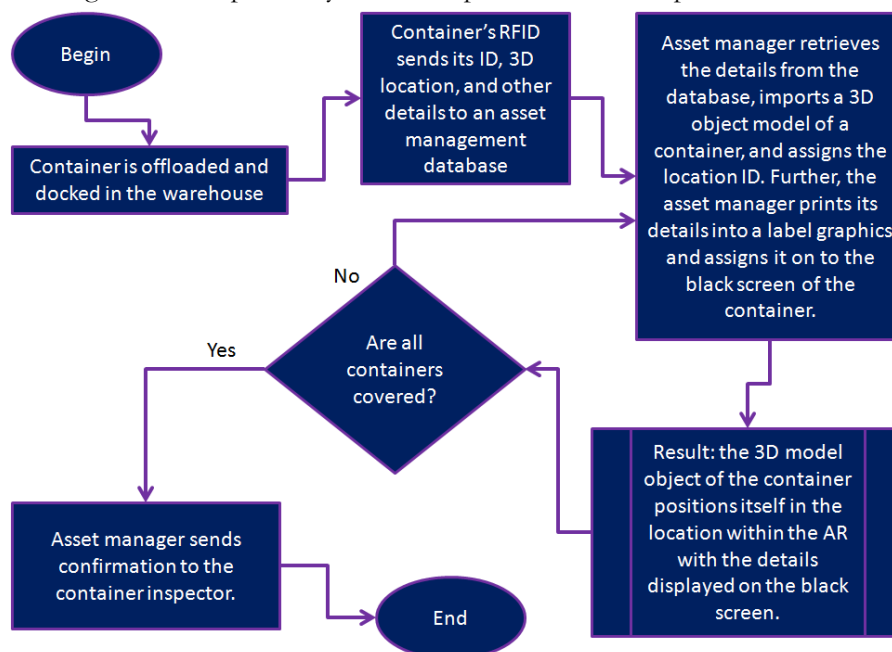

Figure 7: Workflow for asset accounting in AR of containers reaching a construction warehouse

When all the containers are offloaded and docked, the asset manager may assign the container IDs to the inspector. The inspector shall then complete the steps as presented in the previous section. In this AR application, RFIDs are deployed to make the containers smart which could be possible because the real layout of the warehouse was mapped with the VR layout (Sun, Wei, & Kaufman, 2016). The containers could communicate with the asset management database to transmit their natively stored data and also the location data after they were docked (Schniederjans, Curado, Khalajhedayati, 2020). However, two manual steps by the asset manager were added to enable the containers in the AR application within Blender Software. Automatic vehicles may be configured to follow the constrained path of the cameras deployed as observers (Bechtsis *et al.* 2018). Constrained paths can be configured to avoid collisions by assigning dedicated paths to the vehicles. The vehicles may be inducted as VR meshes having the cameras parented to them. Hence, when the snap command is executed, the real vehicle quickly knows about the destination 3D location coordinates and reaches it following the constrained path it has been allowed. More applications are possible using the AR thus formed. For example, when the containers are opened the unpacking and movement processes can be tracked within the same AR provided every package is assigned its own dedicated RFID. If RFIDs are assigned to storage bays, this AR setup can be expanded to control storage of packages, as well.

This scenario can be expanded to a complex warehouse having multiple inspection vehicles, either running on dedicated paths or crossing paths. In such a scenario, dynamic vehicle routing may be conducted using the AR application (Cirulis & Ginters, 2013; Merlino & Sproge, 2017; Agha, Venancio, & Barlasakli, 2020). The vehicles need to be smart and should be able to access location data of other vehicles moving in the vicinity. Thus, when two vehicles are about to cross paths, one of them stops based on an estimation that the other one may reach the cross road faster. More complex rules can be applied to ensure that the vehicles never collide.

6   Conclusion

AR application can be used for effective and accurate management of a temporary construction warehousing facility. By accurately mapping the physical warehouse layout with a 3D map, the warehouse can be transformed into a smart facility. A wireless network connected to an asset management database can ensure that smart containers can populate it after getting offloaded and docked. By following two simple steps, the asset manager can quickly enable the smart containers within the AR application and assign them for inspection. The inspector can run the AR in a handheld display and can accurately locate all containers and match the data between the physical containers and their virtual label and database entries. The vehicle use by the inspector can be driven automatically using path constraints of the observer camera. In real warehouses, multiple vehicles can be configured to carry out the inspections. Further, this setup can be used for other applications in smart warehousing.

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