Indoor Navigation with Augmented Reality and BIM: A Marker-Based Approach for Locating Logistics Areas on Construction Sites

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Abstract: A significant part of the working time on a construction site is spent searching for materials. Unnecessary distances are covered because the logistics areas for storing components are distributed over several floors and areas, depending on the size of the construction site. This paper proposes an augmented reality logistics app for smartphones that navigates a user to a desired logistics area on a construction site. The logistics app was developed with the Unity game engine based on the augmented reality framework ARFoundation and ZXing, a library for recognising QR codes. Solely the BIM model of the building to be constructed, which contains the 3D geometry as well as the position of the logistics areas and the QR codes, serves as the data basis for navigation. Since no further processing is necessary, the logistics app can be easily adapted to new building conditions. The demonstrated linking of BIM with marker-based indoor navigation and augmented reality facilitates the targeted search for material on the construction site and improves the logistical information flow on a construction site.

Keywords: BIM, Construction Logistics, Indoor Navigation, Augmented Reality, QR Code

1 Introduction

Construction logistics deals with the planning, control and monitoring of material and information flow on a construction site [1]. It is an important discipline in the realisation of construction projects and contributes significantly to the efficient and effective implementation of construction projects [2]. In the context of increasing cost pressure, the lack of skilled workers and the increasing specialisation of the companies involved, it is important to increase the productivity of the industrial workers and to improve the cross-trade information flows on the construction site. According to [3], around 25% of the working time in building construction is spent on avoidable activities such as manual transport, searching for materials and unnecessary routes. The high number of involved companies leads to vertical and horizontal breaks in the value chain [4]. This favours the loss of logistically relevant information.

This paper aims to improve the flow of information in construction logistics by linking augmented reality (AR)-based indoor navigation with Building Information Model (BIM) planning data. A developed logistics app reduces unnecessary travel times on the construction site when searching for materials.

2 Technical Basics

2.1 Augmented Reality

Augmented Reality (AR), like Virtual Reality (VR), is a form of Extended Reality.

Regarding the distinction between AR and VR, [5] states that AR "is a variant of Virtual Environments (VE) or Virtual Reality as it is more commonly called. VE technologies fully immerse the user in a synthetic environment. While immersed, the user cannot see the real world around them. In contrast, AR allows the user to see the real world, with virtual objects superimposed on or merged with the real world. Therefore, AR complements reality rather than replacing it completely." [5].

[6] distinguish between six different types of AR and classifies them as "triggered" as well as "view-based". Trigger-based AR, for instance, relies on markers or objects and GPS positioning, which initiates the visualisation of augmented objects. In contrast, with "view-based" AR, there is no matching between the real world and the augmented objects.

2.2 Indoor Navigation

There are various approaches to indoor navigation with AR. Depending on the use case, different positioning methods are conceivable. They are divided into three categories by [7]: marker-based methods, 2D image recognition-based methods and 3D space recognition-based methods. Marker-based methods aim at synchronising between reality and the augmented objects to be placed. For example, QR codes can be used to achieve such synchronisation by placing QR codes in the real world and linking them in the AR application.

With 2D image recognition-based methods, the real environment is screened for distinctive objects. If the position of possible objects to be recognised is known in a stored model, the location is determined if the recognition is successful. [7] note that this approach has weaknesses in the case of many and very similar objects. In addition, external factors play a role (angle of view of the image, distance to the object, moving objects).

Methods for 3D spatial recognition are used to capture spaces and match them with the cubature of stored spaces. For instance, a recording is made as a point cloud model. This approach is considered accurate, but also time-consuming and inflexible. If a location is heavily frequented or if individual rooms are very furnished, methods for 3D spatial recognition reach their limits.

[8] summarise the use of common positioning systems for indoor navigation (GPS, infrared, Wi-Fi, Bluetooth, ZigBee, NFC). They differ in terms of accuracy, operating location (indoor, outdoor), power consumption and costs. Only with NFC (near field communication) is it possible to determine a location with an accuracy of a few centimetres. Otherwise, the range is between 1m (infrared, Wi-Fi) and 10m (GPS).

2.3 Using Augmented Reality for Indoor Navigation in Buildings

In the scientific literature, very different proposals for using AR in buildings can be found, especially public buildings with much public traffic such as hospitals and shopping centres. As early as 2014, using the example of a hospital, [9] showed that navigation using AR is faster than orientation using maps or floor plans. [10] use the SLAM algorithm (Simultaneous Localisation and Mapping) to create and match point clouds. In contrast, [11] and [12] deposit two-dimensional maps in the application to enable pathfinding. [8] combine both approaches by initially creating a point cloud model and entering it into a content management system. There, navigation points are added and floor plans are exported. The data can be accessed from a cloud and coordinates are exchanged as JSON files. [7] propose a marker-free system by attaching Bluetooth transmitters (beacons) to the ceiling. All applications have a similar user interface. The user selects one of several predefined destinations on his smartphone, then his location is determined and his path is indicated by augmented lines or arrows on the floor.

At present, AR does not play a significant role in construction logistics. Nevertheless, approaches to simplify the process of component delivery through digital methods have existed for a few years. For example, the start-up Schüttflix [13] provides a GPS tracking system for delivering building materials. The unloading location is identified using a photo. The construction company Strabag uses a specially developed digital component tracking system based on QR codes [14]. Each component is marked with a corresponding QR code. The element status can be recorded and changed via an app. Contract documents, deadlines, etc. can be viewed for each component on an online platform. This makes it possible to compare the actual and target status.

3 Requirements for the logistics app

[4] mention the following particularities of construction logistics that need to be considered:

There are limited possibilities for storing material on the construction site. For this reason, the aim is to deliver building materials to the construction when they are needed. Before placement, the delivered building material should be stored as close as possible to the placement site, considering assembly, construction and movement areas. Thus, in building construction, the material is distributed over several floors and building areas. For construction logistics and executing companies, it is consequently not possible to maintain a simple visual overview of the material stored on the construction site. The individuality of construction projects (individual production and temporary location) and daily changing construction conditions make orientation on large construction sites difficult, as walkways and storage areas change regularly during the course of the project. To reduce the time spent searching for materials, it is therefore advisable to support the project participants with an indoor navigation tool. Due to planning changes during the construction phase, the basis of such an indoor navigation tool must be based on current planning data. The fluctuating availability of materials and construction personnel leads to unpredictable changes in the construction process, which influence the data basis of the indoor navigation tool. Furthermore, the highly fragmented industry structure results in many different project participants who need to be supplied with information as efficiently as possible. On the one hand, the logistics app should be as intuitive to use as possible and the information should be presented in a way that is as easy to understand as possible. On the other hand, no additional effort should be required on the part of the logistics planners or site managers to maintain the content.

This leads to the following requirements for the logistics app:

- Increasing productive working time by reducing search and travel times

- High topicality of the used data basis

- Low implementation effort, e.g. through the use of BIM data

- Low training costs

4 Logistics app to support construction logistics

Based on the requirements for the logistics app, an application concept was developed. It supports the project participants in their search for building materials or logistics areas on a construction site. The use of mobile phone-based AR techniques enables a widely accessible and easy-to-understand navigation in the building.

A logistics server will provide the navigation data for the logistics app. In addition to the building geometry and semantic component information from the BIM, this server contains current planning data for the construction process and logistics planning as well as the status data of the suppliers who deliver to the construction site. It is assumed that the logistics planning created has been adapted to the conditions of the different construction stages and also considers temporary assembly and construction areas. Through the use of the logistics server or an extended BIM platform, the app has an up-to-date and shared data source. This improves the exchange of information between the project participants. Via a web API, the logistics app can query the required data and update its data status (see Figure 1).

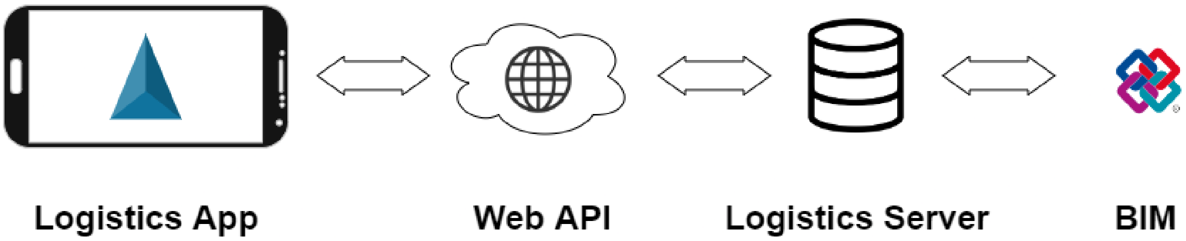

Figure 1: Components of the Logistics App

4.1 Combining BIM and Indoor Navigation

The basic research showed that various possibilities for indoor navigation and positioning using AR exist. This application uses a marker-based approach with QR codes, as the locations of the QR codes and the logistics areas can be implemented directly in the BIM software used and then imported into Unity. Even though, for example, [7] mention the disadvantages of QR code markers such as the lack of protection against the weather, the productive application of QR codes even under weather conditions by Strabag [14] shows that QR code markers are robust enough. Moreover, in the present application, they are used exclusively for positioning and can therefore be attached to fixed, immovable construction elements such as columns or walls. Another argument against the use of 2D- or 3D-based positioning methods and in favour of the marker-based approach is that due to the construction progress and the rapidly changing local conditions, point cloud models, for instance, quickly become outdated and would have to be updated in a time-consuming manner. For these reasons, a construction site does not offer any meaningful clues for image recognition either.

The logistics app was implemented as a demonstration application using the Unity game engine. The AR tracking is carried out via the AR Foundation Framework. This framework makes it possible to track the position of an AR device in the real world via acceleration sensors and recorded camera images and to pass this information on to the AR application. A comparable concept for indoor navigation with Unity, but based on AR-Core, was pursued by [15]. The library of ZXing [16] is used for QR code recognition.

The BIM planning data is integrated using scripts that assign the necessary semantic content to the imported 3D geometry in the FBX format. Thus, the logistics storage areas are stored as target locations in the navigation and calibration locations previously defined in the BIM are stored as entry points in the logistics app. To use the application on the construction site, the defined calibration locations must also be marked in the real world using QR markers. Components that remain unchanged over several construction stages, e.g. Kanban-Boards are suitable for this purpose, which are used in Lean Construction Management to visualize the work at various stages on site.

4.2 User Interface of the Logistics App

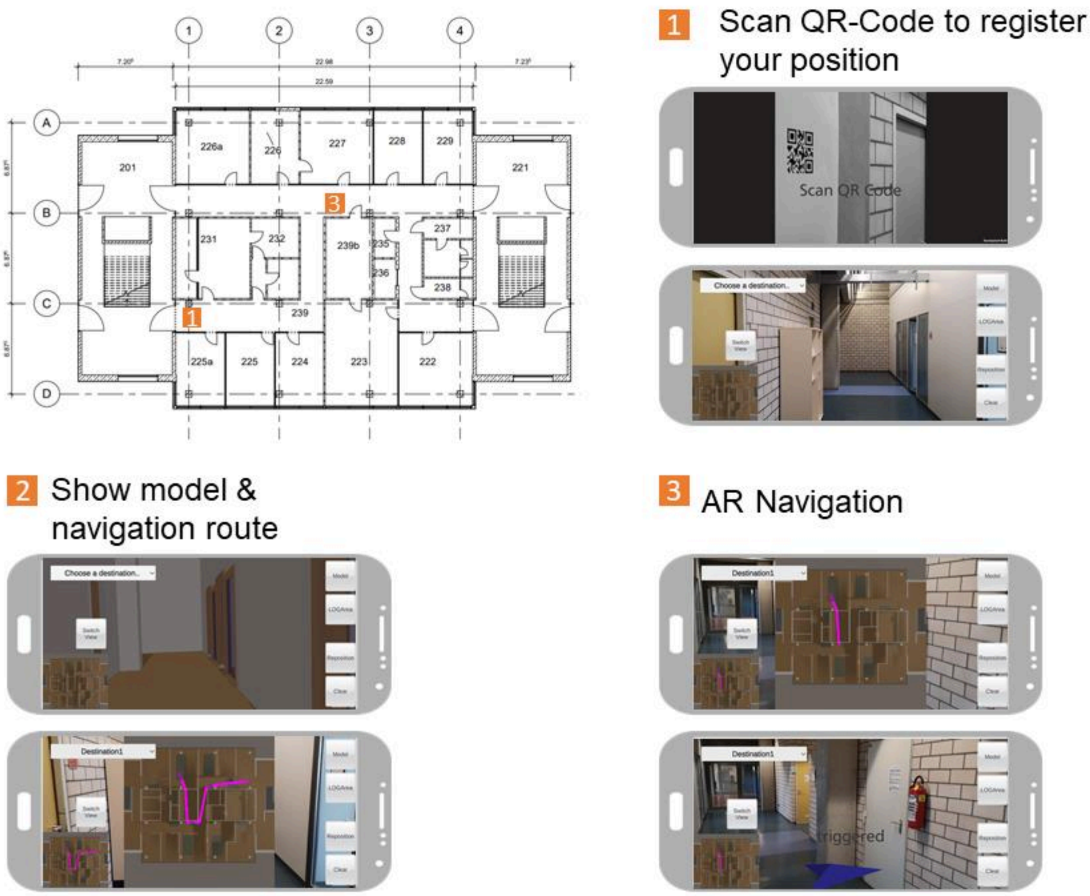

Figure 2: Exemplary Usage of the Logistics App

In the following, two application scenarios are outlined for the usage of the logistics app:

In the first case, a construction site logistics employee receives the delivery of materials. According to the stock planning, this material delivery is to be distributed to the logistics areas on the individual floors. To support the employee in finding the correct logistics areas, he can scan a unique component code on the material packaging and is guided to the correct storage area by the logistics app with the help of augmented arrows (see Figure 2).

In the second case, an employee of an executing company is in the building and is looking for more material to be installed. The logistics app shows the delivery status of the ordered materials and the storage location on the construction site. The logistics app directs the employee to the logistics area with the materials she is looking for in the building (see Figure 2).

5 Conclusion and Outlook

The logistics app shows that a BIM-based AR application for indoor navigation simplifies the search for materials and logistics areas on the construction site. In practice, only an occasional "drifting" of the AR camera in the application occurred, which was due to inaccurate positioning. This could be circumvented with more recalibration points, but this means more "maintenance effort" on the construction site.

Furthermore, temporary "blockages" of the paths in the building by supports or similar have not yet been considered when navigating to the desired logistics area. In future, it should be investigated how such closures can be noted in the logistics app and shared with the other project participants via the logistics server.

To provide a comprehensive assessment of the choice and use of a suitable tracking technology on a construction site, a systematic consideration of these technologies should be carried out in perspective. Against the background of different local conditions and construction states, aspects of the integration of outdoor navigation should also be considered.

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