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# Image-based semantic construction reconstruction

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A B S T R A C T

Site layout planning is a crucial task for enhancing the safety and efficiency of a construction project. However, the locations and the number of on-site objects change constantly during construction. Hence, dynamic site layout planning is difficult without a real-time data acquisition method. Therefore, in this research, we develop a method to rapidly acquire the geometric information, positions, and dimension data of construction objects from on-site cameras and then generate a virtual construction scene. This method contains four steps—*projection*, *duplication*, *description*, and *calibration*—and it is incorporated in a novel software tool. The first step, *projection*, establishes a projective model that maps video images to the actual site using cameras. The second step, *duplication*, quickly determines geometries from the video images of the positions and dimensions of a construction in order to build a 3-D model in a geometric virtual construction. The third step, *description*, associates the geometric models with corresponding actual objects to establish a virtual construction scene that incorporates the practical knowledge of engineers. The fourth step, *calibration*, improves the accuracy of the virtual construction for more realistic planning. The developed software tool thus allows engineers to load a video and specify the locations of each filmed object, as well as to specify the properties of the objects. Video images are linked with virtual models via the numerical models created simultaneously from the algorithms in the software tool. In order to verify that our method is feasible, we retrieve closed-circuit television videos from an actual construction site. Using the software, it took users an average of 123.6 s to generate the corresponding virtual construction scene, including three working areas and three on-site objects through the four-step method. Measurements of the dimensions of actual objects and corresponding virtual objects are compared and errors range from 0.2 to 1.2 m. In the fourth step, engineers can use the more accurate, known dimensions of an object to reduce this error to an acceptable range for the needs of a construction site. In summary, the tool we developed allows engineers to re-plan an operation in a semantic virtual construction instead of risking re-planning on the actual site. The tool also has the potential to bring construction simulations closer to reality.

## 1. Introduction

A crucial task in a construction project is the layout planning for the construction site. This planning must address vital requirements such as the locations of the facilities, traffic space, and vehicle accessibility within the limited space [37]. Site layout planning problems are important because they can significantly affect safety, efficiency, and other aspects of a project [7,29,33]. For example, safety is associated with the distance between heavy equipment and other objects. Meanwhile, efficiency depends on the position of resources such as materials, equipment, and facilities. The two most common problems—the location of heavy equipment and the accessibility of vehicles in the limited space of a construction site [34]—are therefore of particular concern.

Since the resources on a site are constantly changing, the site layout is never static. In a dynamic site environment, equipment will enter and leave the site at different times, and the position of site resources will change according to different work demands. Thus, the site layout needs to be re-planned for each important activity to ensure there is enough space for the placement of facilities and vehicle accessibility. Layout planning for a dynamic environment therefore encounters more challenges than it does for a static one. Engineers need to swiftly adapt to situations, creating layout planning for temporary facilities and equipment within a limited space [2]. Under such circumstances, information is needed in real time for engineers to gain a faster and deeper understanding of construction activities [5].

Construction management now adopts more camera techniques by providing real-time site images and video to engineers. Cameras are able to provide spatial descriptions in the left-, right-, far-, and near-fields; however, the existing problems of using cameras in construction management remain. One problem is fragmentation between

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monitoring and planning, which results in difficulties for engineers to access spatial data directly. This fragmentation means that engineers seldom apply cameras in site planning applications, because only using qualitative descriptions of space usage can easily lead to integrity issues [1].

Acquiring quantitative space data expeditiously can aid dynamic layout planning. Cameras are now commonly used on construction sites. When engineers are able to quickly integrate quantitative spatial information, such as data on dimensions and locations provided by cameras, they are able to conduct site layout planning before actual operations. This also expands the existing applications of on-site cameras and benefits dynamic site planning.

## 2. Related research

This section discusses three categories of existing research: (1) on-site data acquisition, (2) virtual construction, and (3) dynamic site planning. The first category is related to the technologies used to acquire on-site data such as equipment positions, which can help engineers clearly comprehend the situation of a site for reliable planning. The second category is related to technologies regarding virtual construction. Virtual construction is a concept that can be used to visualize different on-site scenarios for planning and management. The third category is related to research on dynamic site planning. Research, including various data-acquisition methods and site-planning methods, is reviewed in this category.

### *2.1. On-site data acquisition*

In site layout planning, assisting engineers in understanding the current situation of a construction site is important. For this purpose, cameras, laser scanning, and location tracking sensors are common tools employed to collect data such as location, size, and number of various on-site objects and working areas. These on-site data acquisition techniques can be classified into sensor-based and vision-based methods.

Sensor-based methods collect data by using location-tracking sensors, and have often been used in construction site applications. For example, global positioning system (GPS), radio frequency identification (RFID), and ultra-wideband (UWB) technologies have been used for tracking the location of construction equipment and personnel within sites [10,27,28,35]. Regardless of the specific type of sensor-based method used, each sensor can acquire a large amount of accurate position data; however, they need to be installed on every resource (materials, equipment, and facilities) that requires tracking. Frequent installation and uninstallation of sensors is labor-intensive on a site with a large number of equipment and materials. In addition, it is difficult to obtain size information for an object using only a single sensor, so multiple sensors and additional computation are required to acquire the width and length data of objects. For these reasons, sensor-based methods are not suitable for obtaining the space occupation information of objects on a site with a large number of resources.

Vision-based methods are optical methods that use cameras and computer vision techniques, and include 3-D laser scanning and photography. 3-D laser scanners can rapidly and accurately measure the 3-D shape of an environment, and can collect dense point-position measurements of on-site objects. Researchers have applied laser-scanning technology to generate point clouds of as-built objects and model their geometries [30]. Nevertheless, the cost, need for operational training, and other technical challenges all make laser-scanning technology unattractive in practice [9].

The other vision-based method, photography, has more applications in tracking and recognition on construction sites. It can provide (1) computer-vision recognition, (2) automatic monitoring and tracking, and (3) easy-to-understand evidence for construction operations. A digital camera is one vision-based method that can be installed easily and has the potential to automatically capture the size and position of an object [32]. Brilakis et al. [3] proposed a framework using stereo cameras for 3-D reconstruction. This framework allows a 3-D point cloud and depth map to be obtained. Brilakis et al. [4] also used on-site videos from a set of two or more static cameras to track locations of site resources. They stated that vision-based tracking does not require tagging sensors on each target, and camera views can cover a large area. Ju et al. [17] and Kim et al. [18] developed construction management tools whose data sources are cameras in a closed-circuit television (CCTV) system. This kind of system can provide real-time monitoring to help engineers understand on-site activities. Rashidi et al. [25] proposed a method to automatically find key camera frames. High-quality frames are helpful in building robust 3-D scenes. Jaselskis et al. [16] proposed an approach that increased the mobility of the captured video. In this approach, personnel can wear an equipment bag anywhere on-site and the monitoring results are sent to a person off-site through the equipment bag. In summary, using cameras to acquire on-site data is worthy of our research attention and holds promise. We summarize the research related to on-site data acquisition in Table 1.

**Table 1**
The related research on on-site data acquisition.

| Related research | Methods | Technologies |
|---|---|---|
| Goodrum et al. [10] | Sensor-based | RFID |
| Song et al. [27] | Sensor-based | RFID |
| Song and Eldin [28] | Sensor-based | GPS |
| Zhang and Hammad [35] | Sensor-based | UWB |
| Tang et al. [30] | Vision-based | 3-D Laser Scanning |
| Golparvar-Fard et al. [9] | Vision-based | 3-D Laser Scanning |
| Wu et al. [32] | Vision-based | Photography |
| Brilakis et al. [3] | Vision-based | Photography |
| Brilakis et al. [4] | Vision-based | Photography |
| Ju et al. [17] | Vision-based | Photography |
| Kim et al. [18] | Vision-based | Photography |
| Rashidi et al. [25] | Vision-based | Photography |
| Jaselskis et al. [16] | Vision-based | Photography |

### *2.2. Virtual construction*

One management approach is virtual construction [19], in which the construction scenarios are presented in models, simulations, and visualizations generated through computational methods. This can help engineers identify potential problems that may occur in actual construction processes, such as spatial conflicts and inefficient machine operations [13,20]. As the application of virtual construction is visual and interactive, Nikolic et al. [24] used virtual construction to instruct engineering students on how to visualize and explore 3-D information. The decision-making skills of students were cultivated under this educational virtual construction system.

To create a practical 3-D virtual construction system to help engineers, Zhang et al. [36] indicated that there are four essential elements that must be involved: (1) physical objects (e.g., buildings or equipment); (2) construction information (e.g., quantity, schedule, or cost); (3) realistic 3-D models including geometric and authentic information; and (4) animations to depict the process. These related studies show the potential applications of virtual construction in construction management and the information necessary for implementing it.

In fact, researchers have used 3-D game engines to simulate real scenarios in virtual construction. Game engines typically provide real-time rendering, a scripting interface, a physics engine, sound, animation, artificial intelligence, and networking, which enable simplified and rapid development of interactive models and environments [12]. In one study, Hu and Zhang [15] proposed a method for building virtual assembly applications that take full advantage of 3-D game engines, which is more efficient than traditional technology. It creates a vivid