Augmented Reality (AR) Based Approach to Achieve an Optimal Site Layout in Construction Projects

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Abstract

Site layout planning involves processing and visualizing complex information residing with different team members. Usually, this exercise is carried out using iterative exchange and understanding of information on paper documents and 2D drawings in team meetings. In the present work, it is hypothesized that aiding the project team with an AR based system would help better tap into the insights and experience of team partners. For this, a BIM enabled Android-based AR site layout planning tool was developed. This tool uses marker-based identification and tagging scheme to visualize the construction site. An initial study of the user behavior while using this system compared to conventional systems points that in addition to improving visualization the planners' faculties and experience are employed towards optimization of the site rather than understanding the site layout plan. The study illustrates the utility of using AR/VR in planning processes.

Keywords- BIM, Collaborative Design & Construction, Site Layout Planning, Augmented Reality, Visualization

1 Motivation and Research Objective

Site Layout Planning (SLP) is an initial task to be performed by every planning team on a construction project. Site Layout Planning (SLP) is considered to be laying out temporary facilities (TFs) necessary for future construction in line with route planning. An optimal layout ensures safe working conditions for labors, optimum usage of available space, low activity interference and reduction in on-site travel time. Team members having significant experience in the field of construction are considered most suitable for the layout planning. The task of SLP is equally important for every team or stakeholder of the construction project; since on the site integration of planning is essential and have to be most efficient for a successful project. The multiple operations that happen simultaneously on construction site in addition to the uniqueness exhibited by each project, it is usually not possible to envision every need of the future. Therefore, planners usually resort to certain heuristics, intuition gained with experience on similar projects to come up with the best possible site layouts [1].

At present, the site layout planning (SLP) is carried out based on 2D plans for the site. The paper-based drawings are arduous for planners to plan since they do not offer visualization in 3D perspective. Hence, to get optimal layouts for increasing the efficiency of projects, the collaboration among project teams and stakeholders is very crucial. The ability to anticipate and finding a feasible solution to the site layout remains a key challenge for planners to address. The ability to visualize the site and aggregate experience from the various team members effectively remains a big hurdle in the conventional SLP being followed in the construction projects across the world. Thus, SLP poses key challenges in visualizing the site constraints with respect to SLP on one hand and achieving coordination and collaboration among the various team members. In this context, it is hypothesized that the emerging applications of technologies like BIM and AR in the field of construction might offer a way forward in the right direction as far as SLP is concerned.

Building Information Modelling (BIM) provides an information management paradigm to enable better team coordination, collaboration. BIM technologies enable the maintenance of a single and updated information model for the entire project thus helping the team to plan and execute projects effectively. The distributed nature of the model enable the teams coordinate remotely. Augmented Reality (AR) enables the projects teams to visualize the as planned by enriching the real environment with the digital information. Such visualization of the model is meaningful since it assists in identifying the relevant factors, study the interaction between factors, preparing and understanding alternative solutions. `Thus, combining these two technologies of BIM and AR would provide a potent combination to solve the challenges of SLP.

This study provided the first preliminary steps in this direction. In this paper, the background of the site layout planning is first discussed. The potential of integrating BIM and AR to solve some of the key challenges in SLP are then discoursed. The paper then provides a framework to illustrate how such an integration can happen. A site layout tool with BIM +AR was developed. A preliminary experiment was then conducted to elicit user experience in using BIM+AR tool in site layout planning. The paper concludes with possible directions of research in automating the site layout planning on construction projects.

2 Background

2.1 Site Layout Planning

Construction site planning is among the most intriguing tasks exercised by a project team before execution on site. The process of SLP involves locating temporary facilities on site. The emphasis is on the temporary nature of these facilities that they may be for a short span on site until the specific task associated with its use is completed. Despite this, some facilities remain on a construction site for the whole project lifecycle and are left for future use in the task of operation & maintenance (O&M)[2]. There are several objectives to be met those can result in a good site layout. For example, identification of facilities needed to support construction, positioning such facilities on-site, determination of required size and shape for facility, travel time between facilities and construction site, the frequency of movement of equipment between facilities and from facility to the site are to be considered during the process of SLP. Such objectives to be achieved by the SLP makes this task highly subjective and complicated for the construction managers (CM). Thus to optimize this multi-objective problem CM(s) have to prioritize the functions and apply trail & error method to their priorities in constructing a layout [3]. The necessity for an optimal site layout is not only to provide safe working conditions to workers & minify the travel time but also to prevent a significant amount of money and space that is bound to these facilities at the initial phase of the project. Thus, efficient utilization of the site space has huge implications on both cost and time in a project. The activity of SLP involves several steps including the identification of temporary facility required, shape and size of required facility & fixation of the facility to a particular location on site and estimation of tenure for the facilities at a specified location on the site. These tasks are crucial to every division of the organizations involved in the construction project since it directly or indirectly affects worker's productivity, material deployment, on-site security & cost of construction [4]. For performing this essential and crucial task, it is required to get every project stakeholder on the same platform.

2.2 BIM for Site Layout Planning

Building Information Modelling (BIM) technology is an advanced way to replicate construction project as a real 3D model along with every minute detail associated to project being stored in the database. BIM has made a remarkable accomplishment in countries across the world both in developed economies and developing countries[5]. But a majority of developing countries depict a research gap in BIM context [6]. The concept of BIM emerged over a decade [7][8]. However, there are significant challenges being encountered in the adoption of this paradigm in the construction industry[5]. Eastman *et al* [9] through case studies showed the majority of executed projects lacked in utilizing BIM's potential benefits. The information management component of BIM often referred to the 'I' component makes it different from any other modeling tools. BIM provides a platform to manage and aggregate information from across different disciplines in a digital form which can be used across the project life-cycle including facility management at the end of construction. Such project data associated with the facility to be constructed can comprise of information related to quantity, schedules, estimates, project management parameters, structural analysis and facility management in a single database for collaboration[10]. Such information management paradigm brings the construction industry closer to the 'Computer Integrated Construction' (CIC) model as proposed by Miyatake and Kangari [11]. CIC reflects the concept of having a single source of sharing information.

Apart from the information management paradigm, BIM offers a framework to visualize the information stored in useful ways. This visualization can be geometry of the building as visualized by the 3D rendering of the information in various software tools developed to this effect. Visualization has important implications in terms of construction project management. For example, Sulankivi, Makela and Kiviniemi [12] provided an insight of how BIM can be employed for visualizing site and identifying potential safety issues before time.

Thus, BIM being capable of providing a central source of information aiding in collaboration and visualization as the foresight to prevent potential hazards and make planning effective. BIM have a significant potential to be used for SLP to satisfy the urge of collaboration and visualization. However, the potential of BIM in SLP remains largely untapped.

2.3 AR for Construction Site Planning

The first prototype for AR has been developed in 1968 by Ivan Sutherland and his students at Harvard University and the University of Utah [13]. The term ‘augmented reality’ was coined in 1990 by Caudell and Mizell[14]. The potential of the use of AR is enormous and thus remains an active area of research and innovation in construction industry. The adoption of AR technologies however remains minimal specifically due to the lack of tools which customize the needs of construction industry.

Construction sites are depicted as 2D plans at an early stage during the process of planning. Through these drawings, the planners and managers have to intuitively plan for the project and the temporary facilities required for construction. Such 2D drafts/ Blueprints thus plays a vital role in planning. However, these drawings lack the ability to replicating the same scenario in front of every team member who indulges in planning. This can be due to various factors like difference in intuition level, experience, the state of mind and exposure to the field of planning. Hence, to eliminate the misinterpretation and miscommunication among the teams during the planning the 2D drawings; it is proposed that such planning processes can be enriched by 3D BIM models for the project along with supporting facilities required.

Earlier, the field of AR has been investigated for improving on supervising construction i.e. comparing as planned and as build also called as progress monitoring and for defects detection too [15]. Gheisari *et al* [16] studied ‘Augmented Panoramic Environment’ capable of taking building information to site for understanding the user requirement and human-computer interaction related issues. AR implementation for facility management (FM) has also been an area for researchers and have provided substantial results.

3 Integrating BIM and AR for SLP

Gheisari and Irizarry [17] highlighted the application of augmented reality for facility management along with highlighting how the integration of BIM and AR can aid in the discipline of facilities management. There have been several research studies, which illustrate the possibilities of AR for construction site demonstrating it as a tool for achieving collaboration in construction projects.

Gu *et. al* [18] identified the possibilities provided by an AR integrated BIM server. This study proposed a framework for BIM and AR integration, with more focus on how BIM helps in collaboration. The framework highlights some essential requirements to be considered while looking for integration of these two innovative technologies such as team communication and interaction, data security and visualization & navigation. Wang & Jen [19], Wang[20] highlighted the use of AR technique of visualization to plan a construction site. These studies presented a prototype to visualize virtual site components in real environment by triggering Bi-tonal planar ARTags with a head-mounted display (HMD) V hi-Res800TM (PC) with an InterTrax2TM head tracker device. It was also suggested that use of such prototype and approach along with some rule engine could result in a more sophisticated and effective planning.

Standard processes are seldom used in site layout planning on construction projects [2]. The construction industry still largely approaches the problem of site layout upon experience gained and intuitive level of planners [1]. Thus, the BIM enabled android-based AR application is developed to understand the behavior dynamics during the collaboration between team members and the shift in the approach they employ for SLP.

4 Framework for SLP using BIM + AR

The traditional way of Site Layout Planning involves representation of facility on 2D drawings. These 2D blueprints results are time-consuming to understand 3D architectural scaled model, hard-to-access conceptual design schemes with regards to the building’s surrounding environment, restricts stakeholder’s coordination, limited reusability and low information integration [21]. Thus to address the pressing need for collaboration and intuitive visualization for project stakeholders a BIM enabled Android AR app was developed in the present study. This tool works based on fiducial markers; the 2D construction drawings were used as markers to reduce additional work for generating trackers. These trackers act as a target image to be traced through the developed app to replicate the associated model attached to respective drawing. In this system, an AR environment was superimposed onto 2D drawings enriching them with digital 3D models. The use of marker provided users the ability to manipulate to change the locations of the virtual models while assessing the resultant layout plans with respect to the real-time model. This approach of tracker based AR system enables the user to produce multiple site layouts and finding the best alternative.

The Android application comprises of a dataset containing images of 2D drawings and respective 3D models. The 3D models were constructed using a BIM software Autodesk REVIT. The 3D models were optimized using another modeling and animation software 3ds Max for eliminating conflicts in polygons and vertices. The final step of allocating 3D model with respective blueprints and application development is done using Unity Game engine.

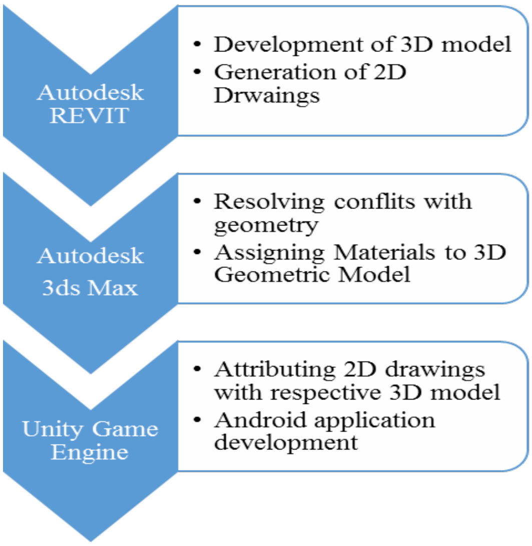

Figure 1: Process and Applications involved in development of tracker based BIM enabled AR platform

Figure 1 illustrates the framework for the development of BIM enable AR platform to this effect. The process involves extracting the relevant information from the BIM model and rendering this information in an AR based engine to develop an application for the SLP for a construction project site.

The Android platform was chosen because of easy availability and its vast user count. To facilitate multiple users at same instance, the application was deployed to the user's mobile handsets enhancing them to move around the scene in the real world. This free movement around the scene was enabled to provide access to full 3D perspective view in one go enabling the user to plan effectively such that no constraint is left unnoticed.

5 Experimental Study

The experiment for this study is designed to observe and contrast user behaviour in an AR based SLP to that of conventional SLP processes. To this end, the experiment was carried out on two teams of engineers with various degrees of experience in site layout planning. The team composition was designed to have people with little or no experience to site layout planning to people with significant experience. Two such teams were formed to test the replicability of the experiment results. Hence, two teams of five construction engineers each took part in the experiment. The SLP experience of the team members ranged from 2 years to 25 years. The dynamics related to user behaviour and the experience were intended to be captured by this setup.

The experiment consisted of four phases. In the first phase, the team carried out SLP with some limited constraints. Second, new information pertaining to SLP was given to the teams and their behaviour in choosing a new site layout plan was observed. The use of two iterations is to have a progressive loading of the information to the team members and understand the change in SLP when new information comes to the team. Third, the team was allowed to carry out SLP using AR based environment with constraints similar to phase one. Finally, the phase two was simulated again in AR based environment.

The aim of the experiment for the team is to determine the location of 5 TFs is each of the phases. These 5 TFs include site office, batching plant for concrete, storage yards for aggregates, fabrication yard for bar bending and parking yard for the construction equipment to be used on site. The possible locations for the TFs included areas in the construction site as well as areas nearby to the construction site.

Each phase of the experiment is time bound. The teams were given 30 minutes in each phase to come up with a possible solution to SLP. The team was asked to provide at least one solution at the end of this time period. The solution comprises of documentation by the team regarding the positions of TFs on the site and surroundings plan (illustrated in Figure 2).

In the first phase, the team members were first given 2D drawings of a hypothetical construction site. The team was then made aware of constraints on utilization of available free space on the site and constraints related to locating TFs on the site space for the permanent facilities are going to be built. The team was allowed to use only 50% of the on-site available space. In addition, the topography of the area was also provided which included terrains and water bodies which might not be suitable for locating the TFs. Figure 2 illustrates the construction site plan and its surroundings as provided to the teams for this purpose. The plan details out the location of the construction site (shaded in grey in Figure 2.) and location of other building surrounding the construction site. It provides the detail of access to the site, provides the general topography of the area and water bodies near the site. In the first phase, the access to the construction site was restricted to just on road which goes between two adjacent buildings to the construction site. Finally, the areas earmarked for TFs outside the construction site were also provided to the team.

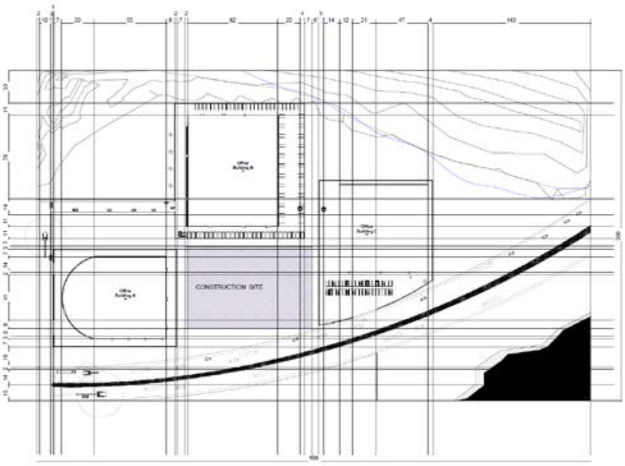

Figure 2: Plan for site with grid-to-grid distance for better understanding the dimensions.

Finally, in addition to the site plan and topography, the plans illustrating the dimensions of each of the individual temporary facilities to be located on the construction site were also supplied to the team to aid their planning processes. Figure 3 depicts the 2D drawing provided, for one of the five temporary facilities described earlier, given to the planners to be utilised for the site layout task.

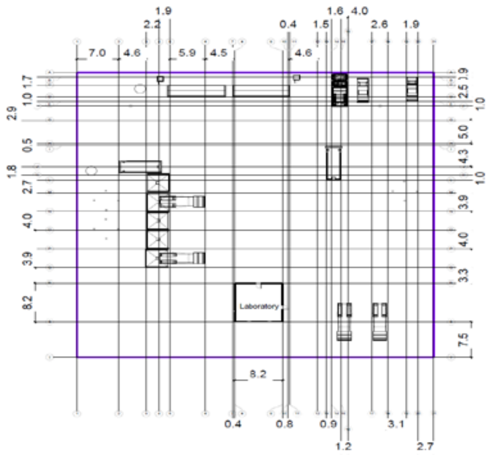

Figure 3: Plan for batching plant for concrete with grid-to-grid distance.

In the second phase, some of the constraints imposed were relaxed. The teams were given twenty minutes to determine the locations of TFs. The constraints on the site utilization for TFs and the access paths to the construction sites were relaxed in this phase. The documentation was similar to the phase one of the experiment.

Once the documentation for the second iteration got over, the team was subjected to phase three involving the use of an AR+BIM based platform for SLP. The constraints for AR platform's first and second iteration were the same as those subjected during the first two phases using 2D drawings. Handheld devices with pre-loaded android-based AR application were supplied to the planning team. Figure 4. displays a screenshot of the augmented reality as experienced by the user when the site's 2D plan drawing was brought in the field of view of the handheld device's camera. Once identified, the AR view is rendered on the 2D drawing on the screen on the user's device. The AR view remains stable as the user moves around the construction site thus offering view from various directions.

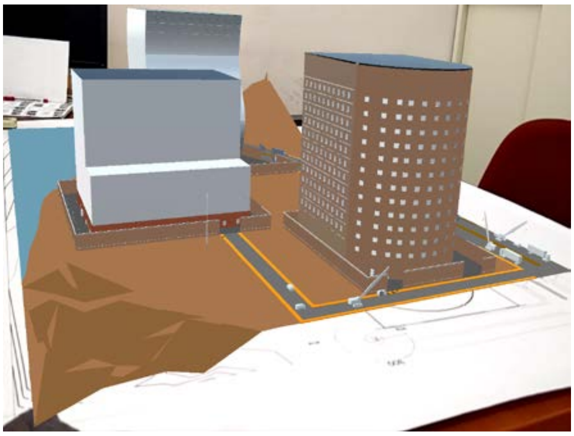

Figure 4: Topography of the site and its surrounding in AR environment.

Markers were created for each of the 5 TFs which were to be located for the project. Figure 5 illustrates the markers and the AR renderings of the TFs. The teams were then allowed to move the markers across the 2D plan of the site and its surroundings to determine what they thought was a good location of the TF. As the team moved the markers, the AR application superimposed the TF on the site plan (illustrated in Figure 6 and Figure 7). The locations of TFs at the end of each phase in AR were automatically determined and documented by the location of the markers on the 2D plan.

During all these phases of the experiment, observations were made on team dynamics with respect to collaboration. The interaction among various team members, delivery of thoughts and ideas by these members, time taken to make other people understand one's idea, time taken to search for a solution, preciseness of the documentation of solution and generation of alternate SLP solutions were noted down. It should be noted that the present study does not infer to the optimality of the SLP solutions generated by the team. The main focus was to understand the interaction, coordination, and collaboration among team members in an AR environment for SLP.

Figure 5: AR rendering of the TFs to be located on the project site

6 Results and Discussion

The experiment provided some key findings in understanding the user behaviour as contrasted in conventional vs. AR based SLP processes.

6.1 Visualization of information

Construction drawings are the main source of information for the planners to perform the complex SLP tasks. The typical 2D drawings help in identifying the dimensions for the available onsite space, facility to be constructed and the topography of the area. For confirming the 3D perspective of any facility, the planners have to refer to at least two drawing sheets (plan and elevation) and stitch the scene mentally. This task of scene stitching is time-consuming since a due attention is also required for the dimensions depicted on the sheet.

It is observed that the experienced persons in both the teams were able to better visualize the site plans than the inexperienced persons. Significant time was spent in explaining the site to the team counterparts. It is interesting that even during the second iteration, again significant amount of time was spent in visualizing what it means when a constraint is relaxed or imposed on the site. Such challenges were non-existing in the AR phases of the experiment. All the team members irrespective of the experience were immediately able to visualize the construction site. The time was more focussed on finding solutions as compared to visualizing the site.

6.2 Explaining the possible solution to team members

The experiment also highlighted the difficulties in explaining the possible solutions to other team members in a conventional environment. During 2D phases of the experiment, apart from visualizing the initial site conditions, for each solution proposed, significant time was spent on explaining that solution to other team members. The consideration of a possible solution rested on how effectively a team member explained the mental vision of the solution to the counterparts and how effectively the various constraints were considered in the solution.

The major challenge for the team members while collaborating using 2D drawing was in presenting their individual viewpoint. It is observed that the understanding of a team member's vision was a significant challenge to other members. It was also observed that sometimes the members did not consider some potential solutions, as they were unclear with the thoughts presented.

Such challenges were not observed in the AR based environment, as the other members immediately understood what the team member was proposing. In addition, it is observed that the team members were more confident that all the team members were perceiving the exact same thing in this environment.

6.3 Experience factors

An interesting dynamics which was observed during the first two phases was that the persons with experience assumed the positions of power in deciding the feasibility and suitability of SLP layouts. The in-experienced team members rallied around the thoughts of the experienced members. Such behaviour might be due the fact that the in-experienced members acknowledged the superior abilities of the experienced personnel in visualizing the solution. Whereas, this dynamic was absent in the AR based phases. The in-experienced persons were more confident on proposing solutions. Thus, in the AR phases, the team members considered a number of solutions as compared to the 2D phases.

6.4 Infeasibility of solutions

The planners master this art with experience, but sometimes the mental visuals perceived might be infeasible as they violate certain constraint not perceived in such mental pictures. The teams spent significant time in discussing a solution which was infeasible under the constraints imposed. During the AR phase, such solutions were quickly discarded as the team immediately visualized that the location violated some height constraint or access constraint etc.

6.5 Solution search

As a result of such dynamics, the teams were more focused on finding solutions in AR phases of the project.

The discussions were more focussed on the implications of a layout on aspects like cost and time. This was in sharp contrast to the time spent in explaining and visualizing the solution in 2D phases. The role of the experienced team members in AR phase was to highlight long-term implications of each solution drawn from experience as compared to aiding in visualization in the 2D phases. Thus, the experience of the members was put to better use in the AR phase of the experiment. As a result, the team could come up with solutions like close spacing of TFs (illustrated in Figure 6) which were discarded as infeasible in 2D phases; and placing in locations which are in proximity but were not visualized in the 2D phases (illustrated in Figure 7).

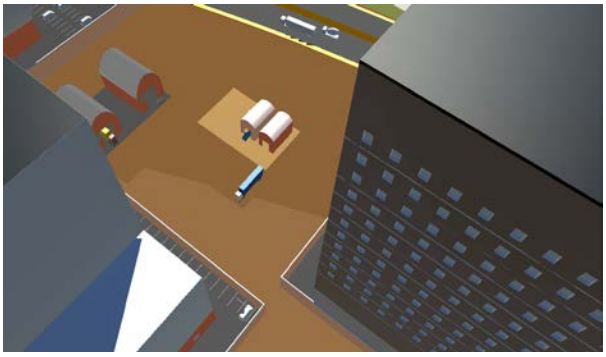

Figure 6: Two temporary facilities accommodated in close proximity.

7 Limitations

The AR based platform suffers from limitations at the present stage. The tracker based AR tool necessitates proper illumination, high contrast texture of target marker and high hardware requirements for the device to deploy the AR application. Loss of information was observed when translating BIM models to AR environment. The present study uses just the massing forms for the buildings. If other details like work-fronts on different storeys are to be considered, there would be a challenge in converting the BIM model to AR renderings. The temporary structures were modeled as regular shape either square or rectangle; restricted the planners involved in the experimental planning task to superimpose the vacant area. This obstruction can be eliminated by dividing the temporary facilities further into small elements. Even after having an advanced setup for deployment, it was observed that the device used for AR application have a delay in time of capturing and image processing. Latency was also detected while using the application restricting the free movement of team members around the scene. These technical challenges should be addressed to make the AR platform more conducive to SLP.

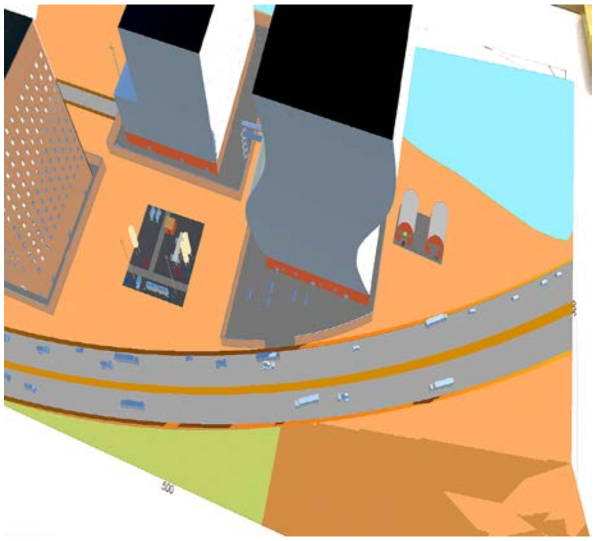

Figure 7: Temporary facilities situated at distance from one another

8 Future Scope

The research can be extended in many dimensions. The SLP can be extended to temporal dimensions in addition to the spatial dimensions covered in this experiment. The AR applications can be augmented by intelligence in generating optimal solution from an initial set of solutions proposed by team members. There is a scope to incorporate such algorithms so as to capture the user experience in generating initial solutions and further optimizing them using a systematic procedure. The application can be made to go markerless and based on object-based tracking to be augmented on a real construction site as was done earlier in case of visualization alone [22]. Further, the possibility of remote collaboration using VR based environment can be explored.

9 Conclusion

SLP is a task for a project team rather than for an individual hence requires collaboration among all teams and coordination of all individuals of the teams. The study highlights the shift in behaviour and approach adopted by teams when allowed to plan a construction site collaboratively in an AR environment. The experiment illustrated the significant potential of AR based applications in improving SLP on construction projects. The AR environment helped the members to evaluate a number of solutions in a given time. The AR platform also improved the effectiveness of the inexperienced planners on one hand and made better use of the experience and intuition of the experienced team members on the other hand.

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