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Adoption of Virtual Reality (VR) for Site Layout Optimization of Construction Projects

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ABSTRACT

Among the significant tasks of construction site management, site layout planning is a crucial activity that influences project success. Currently, the concept of an optimised construction site layout emerges as a result of executing tools and techniques that the construction project management discipline provides. Despite the plentiful existence of site layout techniques, the authors of this paper believe that the incorporation of virtual reality (VR) for jobsite organisation is a valuable and modern management phenomenon for optimal site layout planning. Therefore, the purpose of this paper is to assess traditional practices for site layout planning and introduce the application of VR in construction jobsite organisations for site layout planning, collision detection, and evaluation of construction site layout scenarios. In this paper, two different construction jobsite scenarios for the structural phase of a construction are created and for optimisation purposes, Autodesk Revit software, SketchUp, and Lumion are used to develop the three-dimensional (3D) model. A VR headset is used for testing purposes of the proposed 3D jobsite organisation model. A descriptive case study is examined to describe the proposed organisational plan for the scenarios. In this study, a questionnaire survey has been chosen as one of the research instruments for data collection and evaluation purposes. It is found out that traditional 2D methods used in jobsite layout planning is easier to understand and less time consuming for users compared to 3D VR based jobsite layout organisation. On the other hand, results indicated that 3D VR based jobsite layout planning is more effective to comprehend by users and enhances the ability of collision detection. The results presented in this paper aim to provide industry professionals with a

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better understanding of the benefits and advantages of how VR technology can improve the effectiveness of jobsite layout planning compared to traditional practices.

Keywords: Virtual reality, site layout plan, construction industry, jobsite organisation, 3D model.

1. INTRODUCTION

Regardless of the type and size of the construction project, jobsite layout planning is developed subsequent to a contractor being awarded the bid and prior to the contractor's receipt of the notice to proceed [1]. Planning the site layout of construction projects is a critical task that can significantly affect productivity and efficiency, and hence, the success of the project [2]. Site layout planning is a complex task in the majority of construction projects because of the diversity of decision variables, including but not limited to identification, sizing placing, and coordination of temporary facilities, plants, materials, and people within the boundaries of a construction site [3]. However, due to the heterogeneity of construction activities, that is in the nature of its organisation – project design, time constraints, work areas, environmental conditions, and facility locations, etc. – site layout plans turn out to be unique for each construction project. As the site layout plans are prepared to ensure that work within the construction site progresses smoothly without any obstruction to obtain optimal use of resources and space, preparation of these plans is usually the responsibility of contractors awarded with the job. An effective and systematic approach for planning an optimised site layout plan ensures the optimal use of available workspace, leading to cost and time savings during the construction process, promoting a safe working environment, and providing safe access into and out of the site [2, 4].

According to Ning et al. [5], construction site layout planning has been perceived as a critical step in construction planning by experts and scientists and it is considered to be a decision-making process that includes recognising issues and opportunities, creating solutions, and picking the best option and actualising it. Despite constricted space conditions in inner-city areas, the project costs can thus be significantly lowered by an efficient material flow based on a well-planned layout. Normally every development site is liable to various conditions, variation in the flow of construction work, and the local conditions for each construction project are unique. Nonetheless, in real life practices, site layout plans are poorly developed and lack a strategy for minimising repeated handling of materials [6]. In the study carried out by Sadeghpour and Andayesh, numerous techniques are provided for use in jobsite layout development such as knowledge-based approaches (inclusive of heuristics), mathematical programming approaches (including linear and non-linear optimisation), and artificial intelligence approaches (including neural networks, genetic algorithms, and ant or bee-colony and swarm approaches) [7].

In traditional methods, contractors use two-dimensional (2D) drawings, pdf overlays or hand drawings for developing site utilisation plans. Due to the error-prone and poor methods of the traditional 2D-plan-based approach, this tends to lead to non-transparency and the occurrence of mistakes in later processes. There is no digital control of the planning process taking into consideration the specific fringe conditions at the construction site. Today, digital 3D objects can support those responsible for planning and increase planning performance. Furthermore, it is essential to describe the different construction phases and their dynamic

fringe circumstances and deduce corresponding suitable measures for the planning of supply and material flow [6]. As each construction project is unique, each construction site layout planning process should be treated as such. Therefore, for every phase of a construction project, sequential consideration of assigned resources in producing site layout plan is essential for the effective, safe, and productive coordination of resources and working environment. Combining the logistics plan of a worksite with a digitalised 3D model forms the grounds for comparing different scenarios and constructs an efficient site layout plan that corresponds with every step of the project.

Building Information Modelling (BIM) is being increasingly used in the construction industry to produce n-D data-rich models. Researchers are attempting to use BIM to promote different aspects of the construction process, including the construction site management and the use of on-site models [8-10]. Deshpande and Whitman suggest that the data from BIM can be leveraged to improve the construction site utilisation planning process and enhance communication among all the stakeholders about the construction execution plan. Also, in their work, they discuss the benefits and contents of the tools that are currently being used by industry professionals and inform readers on how to improve existing tools so that BIM models can be effectively used for site utilisation planning. BIM and VR are the two visualisation technologies that refer to the immersive environment and can visually assess jobsite conditions [11].

Different researchers investigated the applications of VR in the areas of the construction industry such as site layout and planning, rehearsing erection sequences, progress and monitoring of construction processes, evaluation of construction scenarios, inspection and maintenance, and fire safety and access assessment [12, 13]. Even though VR headset technology is broadly appreciated in the technology world by its users, not many studies and practices exist that promotes the use of this equipment for construction jobsite organisation. Therefore, the purpose of this paper is to assess current practices for site layout planning and develop a 3D construction jobsite layout plan model using VR HMD technology, also known as a VR headset. The main objectives of this study are to examine the application of VR headsets in construction jobsite logistics/layout planning, demonstrate and compare traditional 2D site plans, 3D model a site plan on screen and 3D site plan a model in a virtual environment, and explore the potential contribution of VR technology for increasing the productivity and efficiency of jobsite organisation. Within this context, existing jobsite planning applications and the use of VR technology is examined, an on-going building construction project is selected and a 3D model of its traditional 2D jobsite layout plan is conceptualised using Autodesk Revit and Sketchup, a generated 3D model is installed on the VR headset, and a questionnaire survey is conducted with numerous industry professional participants to measure and compare the effectiveness of the highlighted models in the following sections.

2. LITERATURE REVIEW

This section provides an overview of the construction jobsite organisation and VR applications in the construction environment. This information will guide the readers to comprehend the applications of VR in construction jobsites.

2.1. Construction Jobsite Organisation

Among the stakeholders in construction projects, it is usually the project manager's responsibility to prepare a site utilisation plan. These plans are normally developed with the knowledge, understanding, expertise, and intuition of the appointed project manager/planner [14]. Planning of construction jobsite utilisation is a significant task that requires a critical review of alternatives so that optimal decisions can be made about where to locate temporary facilities and how to coordinate people, materials, and plants within the work environment [15, 16]. If a site is not effectively and accurately planned by the project management team, problems that lead to time and cost overruns become inevitable. In traditional practice, the development of a competent site utilisation plan is often stricken by project management tasks such as scheduling, construction method in preference, materials, plant, and labour planning [14]. In spite of the vitality of site utilisation planning, it is often done speedily or occasionally disregarded. The results of such acts are reflected in the day-to-day operations of a project, making management of site operations complicated [17].

Poor site layout planning contributes to inappropriate storage within the worksite that can result in materials and product damage, poor siting of the plant, poor siting of temporary facilities, inadequate space provision, unsatisfactory access, security and safety issues, poor wayfinding, demoralised workers, delays, and increased costs. According to Deshpande and Whitman [15] and Kamat and Martinez [18], early decisions made to develop a good site utilisation plan can have a significant impact on the effectiveness of site operations. This study states that ideal site utilisation plans should be developed in a certain way so that the involvement of labour with the movement of materials is minimised. Hence, they can mainly focus on performing necessary construction activities. According to Mincks and Johnston [19], a site utilisation plan should include clearly designated areas on the jobsite for material delivery, material storage, temporary offices and facilities, jobsite access concerning the movement of material within the jobsite and worker transportation, temporary offices, storage facilities, dry shacks, sanitary facilities, temporary water, power, and heat, and jobsite security. Jobsites that are clean and well-organised provide a working environment that has a positive impact on workforce morale and, in turn, results in high production during each work shift. There are various approaches to developing the job-site layout plan and increasing site optimisation. Each approach has to take into consideration the factors and variables that will lead to jobsite productivity as well as successful contract delivery [1, 7].

2.2. Virtual Reality in Jobsite Organisation

VR replaces the real world with a computer-generated environment and has the ability to model future and current realities. With the rapid developments in VR technology over the past few years, the adoption of this technology by construction industry professionals can contribute significantly to the digitisation of construction sites hence, effectively coordinating the resources allocated for each specific project. VR technology can be used as an important tool for jobsite organisation, which comprises a substantial number of tasks spanning from planning to the execution stage. Presently, some construction firms have initiated the use of VR to plan, manage, and construct their projects. Alternatively, VR technology is used as part of a construction firm's marketing strategy as this technology broadens the vision of potential end-users about what output to expect after the completion

of the project. Due to the complexity and the number of factors involved, jobsite developers have adopted novel technologies to improve the efficiency of their tasks. VR technology provides an effective means of verifying site operations as well as site logistics. It allows superintendents to step into the future of their project and understand their requirements and problems long before they occur. Kizil and Joy [20] state that the use of the high-quality 3D environment and dynamic simulation combine to form a uniquely engaging experience. Adoption of VR technology by project management teams enables the visualisation of entire construction jobsite arrangements at different stages thus, providing the workers with a more illustrative site plan by letting them visually see the space utilisation. Jobsite organisation, including traffic routines for equipment, safe working environment, locations for material stock, and manpower availability can also be incorporated into the VR module to be checked visually as part of the logistics plan [21]. Froehlich and Azhar [13] investigated the applications of 3D VR headsets in construction safety and jobsite management. Ebner et al. [6] developed a practice-oriented planning instrument that allows the determination of layout and the equipment for the construction site for the entire running time of the project and it is only changed if needed. Paradoxically, VR technologies are still lagging behind the visions that people have for their use. However, VR has already demonstrated its capacity to change the ways we design, make decisions about, and produce built environments.

3. METHODOLOGY

The focus of this paper is to assess the current understanding about site layout planning through a collective and critical review of literature while building the rationale for why and how VR technology should be considered by decision-makers for production of effective jobsite organisation plans. Therefore, the authors of this article initially performed a comprehensive literature review to investigate the views, perspectives, and practices of site

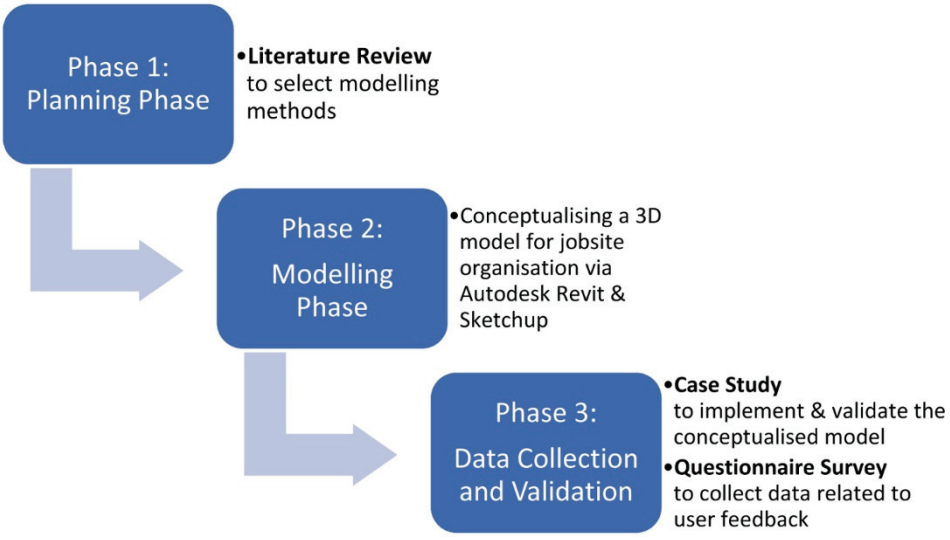

Figure 1 - Sequential Phases of the Adopted Research Methodology

layout planning so that the integrability of VR technology for jobsite organisation and related aspects and challenges can be examined. Figure 1 illustrates the sequential phases of the adopted research methodology.

3.1. Phase 1: Planning

The primary purpose of the planning phase is to identify the existing applications of VR technology in the construction industry. Moreover, examining current practices, aspects, and methods and interpreting them in a specific format so that a 3D model can be established and used for jobsite organisation is also a part of the planning process. At the end of comprehensive literature review, it is concluded that site access, crane placement location, trash waste location, locations of materials, stockpile of excavation, site office, equipment's location, and site orientation are the potential concerns of site layout planning process that can be integrated with VR application for more effective jobsite organisation [2, 3, 16, 18]. As the last step of the planning process, the authors have proposed a conceptual workflow (See Figure 2) that needs to be executed to develop an effective 3D model for application in jobsite organisation.

Figure 2 - Proposed Workflow of the 3D Model for VR Experience

3.2. Phase 2: Modelling

As a part of the modelling process, the initial step was to select a specific construction site where the parameters mentioned above in the planning phase for the jobsite layout planning process were incorporated so that a 3D model could be established accordingly for implementation purposes.

Figure 3 - Location of the Selected Construction Site

Figure 4 - View of the Main Access Point

For that purpose, the jobsite of a university building construction in the heart of Famagusta (located in Cyprus) city centre is selected to measure the effectiveness of VR technology for this specific construction site's layout organisation. The budget for the selected project is approximately $4.5 million, and it is nearly 9,000m². The project is planned to be completed on a tight schedule, 11 months after its start date on 20/10/2016. The location of the site is given in Figure 3 and Figure 4 illustrates the site access point from the main road.

After selection, two different scenarios for the construction jobsite organisation of a university building project are proposed for developing the 3D models. With the help of Autodesk Revit 2018, SketchUp 2018, and Lumion 8 software, two different 3D models for the structural phase of the building construction are generated, so that the practicality and efficiency of a VR box headset for developing a precise jobsite layout organisation model are tested and verified. Subsequently, modelling of the main building's structural frame is performed by Autodesk Revit. A generated model is then saved in AutoCAD file format and exported to SketchUp, which provides a wide range of objects from its warehouse. After placing the necessary construction equipment and objects on the jobsite, the 3D model is finalised. Due to its rich object warehouse, SketchUp software contributed significantly to the actualization of the 3D model as it presented the model in a stronger imaginable format. After that, the 3D model is uploaded to Lumion software for the final rendering. A screenshot taken from the Lumion rendering software that illustrates the 3D construction jobsite organisational plan model is depicted in Figure 5. Using the different software packages enabled us to include more detailed features in our model.

Two different jobsite organisational plan scenarios are built based upon the 3D model outputted by the Lumion software. The first scenario is the creation of a 3D model for the actual jobsite organisation plan, which was established by the decision makers of the university building construction. In the second scenario, the actual jobsite organisational plan is modified, and some alterations, such as a change of the site access point, crane placement location, trash waste location, material storage locations, a stockpile of excavation, site office, equipment's location, and site orientation are made. After modelling the different scenarios, VR headsets are used for observing and comparing the scenarios. A 2D site plan

and the 3D site plan are modelled based on two different scenarios as shown in Figure 6 and Figure 7. Scenario 1 differs from Scenario 2 based on the site access (entrance and exit), the location of the site office, parking areas, equipment location, crane placement, material locations, trash waste access, and a stockpile of excavated soil. The 3D site model of the two scenarios is used for the VR experience. A 3D site plan model is also created including more features of visualising tools that will enable the observer or viewer to explore the 3D model and also have a real-life experience. In the 3D site plan model, equipment, materials, and other components that are present at the construction jobsite are shown clearly, in detail from the rendered model as shown in Figure 8 and Figure 9.

Figure 5 - 3D Construction Jobsite Organisation Model

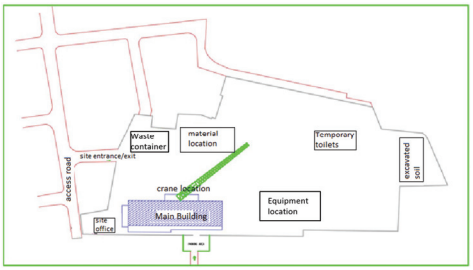

Figure 6 - 2D Site Plan for Scenario 1

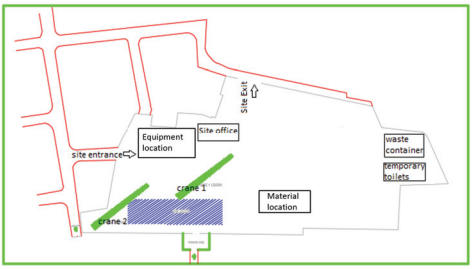

Figure 7 - 2D Site Plan for Scenario 2

Figure 8 - 3D Site Plan Model for Scenario 1

Figure 9 - 3D Site Plan Model for Scenario 2

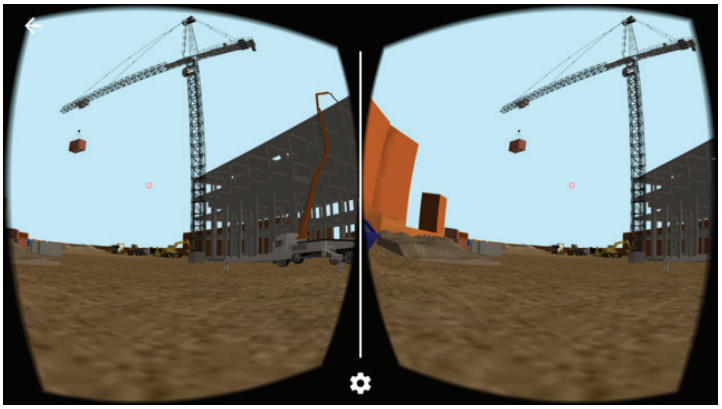

Figure 10 - User's View through the VR Headset for Jobsite Scenario 1

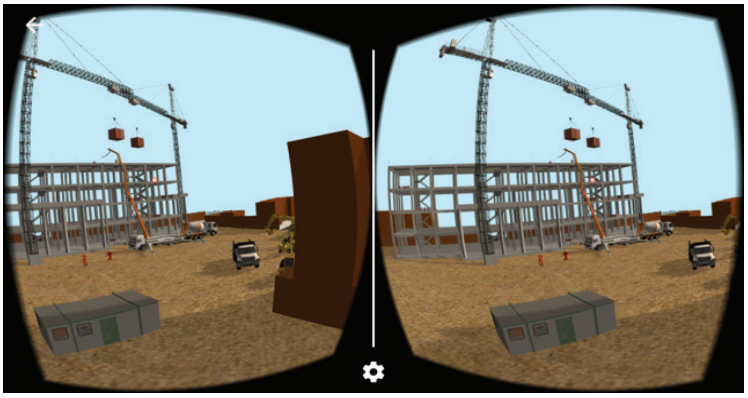

Figure 11 - User's View through the VR Headset for Jobsite Scenario 2

The two 3D site plan scenarios are used for the immersive environments that provide the VR experience for the user. A 360-degree view of the virtual world is experienced through the VR box, through which the user can engage in observing the simulated construction jobsite model. Figure 10 depicts the user's view for jobsite Scenario 1, and Figure 11 shows the user's view for jobsite Scenario 2.

3.3. Phase 3: Data Collection and Validation

In order to measure the reliability of the proposed 3D modelling and integrability of the VR headset technology in designing jobsite organisation plans purposive sampling method was used. This method is described as a type of sampling method in which researcher determines the target population through literature review [22]. In addition to purposive sampling method, through personal communication, experience and observations within the

construction sector, 102 industry professionals who are currently using methods similar to proposed framework or whom have the potential to implement this framework are identified. As given in Table 1, field of expertise of the selected participants are composed of engineers, architects, project managers and supervisors. Having participants who practice at different phases of the construction such as planning, executing and controlling for assessment of the proposed framework is believed to enrich this study. Job positions of the participants by the time this questionnaire was conducted is presented in Table 1.

Subsequently, participants are asked to monitor, assess, compare, and rate the effectiveness of the aforementioned university construction site layout plans established in 2D, 3D and 3D in VR with respect to how they perceive and would asess the process. Their ratings are performed based on a Likert scale of 1 (highly ineffective) to 5 (highly effective). The overall ratings of the participants are interpreted to be categorised as high if ≥ 80%, medium if between 60–79%, and low if ≤ 59%.

Table 1 - Demographic Structure of the Participants

Position	Field of Specialisation	Average Years of Experience	Number of Participants
Assistant Site Supervisor	Construction Management	4	8
Revit-BIM specialist	Design Management	5	7
Assistant Site Engineer	Construction Management	3	11
Site Engineer	Construction Management	5	12
Site Supervisor	Construction Management	4	10
Architect	Architectural Design	5	11
Design Manager	Design Management	6	10
Construction Manager	Construction Management	7	11
Structural Site Engineer	Structural Engineering	6	10
CAD specialist	Architectural Design	5	12

4. ANALYSIS AND DISCUSSIONS OF THE RESULTS

In this section, according to the views and opinions of the participants, their ratings on the effectiveness of the proposed site layout planning models (2D, 3D, and 3D in VR) are presented and discussed. Table 2 provides the opinions of the participants for the 2D site layout plan of the university building construction. For both scenarios, ease of use and perceived usefulness of the traditional 2D site layout plan, as well as comprehending how works and related resources will be coordinated within the site, gained the highest average rating from the participants, at 4.1 out of 5. On the other hand, the majority of the participants accept that the 2D site plan (1.9/5) developed for scenario 2 was insufficient, as they believe it might not be possible to detect potential collision between the two tower cranes used on

site. Participants have a different opinion concerning the adequacy of the 2D site layout plan for improving the accuracy of jobsite organisation. Some of participants have a moderate response regarding whether 2D site plans provide adequate details of the site planning such as locations of temporary facilities, equipment and materials, as half of the participants have given a rating of 3 for this statement.

Table 2 - Results for Demonstration of Scenario 1 and 2 on 2D Site Layout Plan

	Questions	**Participants Rating (Frequency)**					**Average Rating**
		5	**4**	**3**	**2**	**1**	
1	How easy is the 2D site plan to understand?	39	42	12	9	0	**4.1**
2	How effectively does the 2D site plan facilitate the evaluation of two different site plan scenarios?	14	18	41	29	0	**3.2**
3	How effectively does the 2D site plan indicate variations of proposed jobsite organisation scenarios (1 and 2)?	28	41	33	0	0	**3.9**
4	How efficient is the 2D site plan regarding providing a vision of the expected jobsite organisation in reality?	4	10	15	47	26	**2.2**
5	Is the 2D site plan developed for scenario 2 effective in terms of detecting a potential collision of the two tower cranes?	0	0	27	39	36	**1.9**
6	How well does the 2D site plan show the distance between the tower cranes and the location of the material?	0	35	43	15	9	**3.0**
7	To what extent can the 2D site plan help in improving site layout accuracy?	3	12	44	43	0	**2.7**
8	How well do the 2D site plans show the volume and amount of spaces on site?	5	21	47	29	0	**3.0**
9	To what extent do the 2D site plans provide decision makers with the location details of temporary facilities, equipment, materials, and workflow within the site?	4	18	51	23	6	**2.9**
10	How would you rate the overall effectiveness of a 2D site plan for the proposed jobsite organisation scenarios?	9	22	43	28	0	**3.1**

The participants' ratings on the effectiveness of a 3D site layout plan for both scenarios are presented in Table 3. According to the respondents, the difficulty level of comprehending a 3D site layout plan is above moderate, with an overall rating of 3.9. Moreover, participants believe that site plans developed on a 3D platform contribute greatly to obtaining an effective jobsite organisation plan. When overall ratings of the 2D and 3D site layout plans are compared, participants perceive 3D plans as a more effective instrument since the average rating is 3.9 for the 3D plans, whereas it is 3.0 for the 2D plans.

Table 3 - Results for Demonstration of Scenario 1 and 2 on 3D Site Layout Plan

	Questions	Participant Rating (Frequency)					Average Rating
		5	**4**	**3**	**2**	**1**	
1	How easy is the 3D site plan to understand?	32	41	19	10	0	**3.9**
2	How effectively does the 3D site plan facilitate the evaluation of two different site plan scenarios?	30	47	25	0	0	**4.0**
3	How effectively does the 3D site plan indicate variations of proposed jobsite organisation scenarios (1 and 2)?	21	52	26	3	0	**3.9**
4	How efficient is the 3D site plan in terms of providing a vision of the expected jobsite organisation in reality?	18	49	30	5	0	**3.8**
5	Is the 3D site plan developed for scenario 2 effective in terms of detecting a potential collision of the two tower cranes?	19	38	43	2	0	**3.7**
6	How well does the 3D site plan show the distance between the tower cranes and the location of the material?	29	55	18	0	0	**4.1**
7	To what extent can the 3D site plan help in improving site layout accuracy?	22	51	20	9	0	**3.8**
8	How well do the 3D site plans show the volume and amount of spaces on site?	17	44	37	4	0	**3.7**
9	To what extent do the 3D site plans provide decision makers with the location details of temporary facilities, equipment, materials, and workflow within the site?	32	49	21	0	0	**4.1**
10	How would you rate the overall effectiveness of a 3D site plan for the proposed jobsite organisation scenarios?	36	59	3	4	0	**4.2**

Results obtained from the 3D jobsite model testing using the VR headset are given in Table 4. First, participants rated the ease of use of the VR system (VR headset) as 2.9. This may be chalked up to the fact that evaluators who have engaged in testing procedures of the 3D model by adopting VR headsets are novice users of this instrument and, due to the complexity of adjusting the headset lenses sideways to provide a clear view for the users to avoid a double image effect and a blurry view through the headset, they may have faced difficulties. One of the participants commented further and stated that the assessment of the system is a bit slower, but it enables anticipation of the reality of the site conditions and restrictions. With a 4.4 mean rating value, participants indicate their belief for the high potential of VR technology for checking problems in the construction jobsite that may arise due to poor jobsite organisation. For Scenario 2, participants are provided with a set of screenshots obtained by the VR headset and asked to observe a collision between two cranes. The materials' stacked location is rated as 3.9 concerning the competency of the VR headset in assisting the visualisation of the distance between the crane positions. This rating proves that

most of the participants can visualise the materials in relation to the crane placement location on site. The effectiveness of VR in evaluating the two different jobsite scenarios showed a high rating of 4.2.

VR technology can be used in the evaluation of different construction scenarios. This finding proved that VR technology could be used in different construction site scenario evaluation. Overall, the results indicate that the participants are satisfied with the effectiveness of the 3D model showing the narrowness of jobsite access. The VR system enables users to be immersed in the virtual construction jobsite environment and to view the environment in a 360˚ platform; hence, users are able to observe a realistic experience of reality. It is concluded that most of the participants agreed that VR provides users with real-life-like experience. As a part of this study, most of the evaluators observed the distance between the temporary facilities and the working area through the VR headset. The participants' responses in Table 4 indicate that evaluators are satisfied with the level of detail of the 3D CAD jobsite model in VR, and also that the applicability of VR technology in construction jobsite organisation, which includes studying the site layout plan, the evaluation of different scenarios, and collision detection is found to be promising.

Table 4 - Results of the 3D Jobsite Model Testing Using VR Headset

Questions		**Participant Rating (Frequency)**					**Average Rating**
		5	**4**	**3**	**2**	**1**	
1	How easy is the VR system (VR headset) to use?	9	17	34	39	3	**2.9**
2	How effectively does the VR headset help in checking and verifying problems in jobsite organisation (e.g. a collision between two cranes)?	44	52	6	0	0	**4.4**
3	How well does the VR headset help in identifying that the materials stacked location is far from the second crane in Scenario 2?	29	35	38	0	0	**3.9**
4	To what level of extent does a VR headset provide a better understanding of what to expect on site?	31	44	23	4	0	**4.0**
5	How effectively does the VR technology facilitate the evaluation of two different site plan scenarios?	38	51	13	0	0	**4.2**
6	How well does the VR system help in identifying that the site access (entrance/exit) is too narrow for two trucks to pass at a time?	42	53	7	0	0	**4.3**
7	How well does the VR system help in checking the crane placement location in both scenarios?	35	46	19	2	0	**4.1**

Table 4 - Results of the 3D Jobsite Model Testing Using VR Headset (continue)

Questions		Participant Rating (Frequency)					Average Rating
		5	**4**	**3**	**2**	**1**	
8	To what level of extent can the VR technology help in improving site layout accuracy?	27	39	29	7	0	**3.8**
9	To what level does a VR headset enable the user to feel a life-like experience?	43	50	9	0	0	**4.3**
10	How effectively does the VR headset help in showing that temporary toilets are located far from the working areas?	28	43	27	4	0	**3.9**
11	What level of possible advantages does the VR headset offer in jobsite orientation?	31	47	24	0	0	**4.0**
12	What extent is the level of jobsite organisational plan detailed through the VR headset?	29	58	12	3	0	**4.1**
13	To what extent do you think the VR headset is beneficial when determining construction jobsite organisation?	36	55	11	0	0	**4.2**
14	How well does the 3D VR jobsite model show the volume and amount of spaces on site?	30	49	21	2	0	**4.0**
15	What is the overall rating of the VR technology (VR headset)?	45	54	3	0	0	**4.4**

4.1. Comparison of the Three Construction Jobsite Models

In this study, for the two aforementioned scenarios, three different jobsite layout models are developed, and the participants (comprised of construction industry professionals) are asked for their opinions on the effectiveness of the models via questionnaire survey so a comparison of the models can be progressed. As Figure 12 illustrates, the participants' responses are aggregated for relative frequency.

As depicted in Figure 12, for the questions related to the comparison of the three proposed models, the relative frequency of the 2D modelling is ranked as the least advantageous option. Regarding the detection of the distance between cranes and the location of materials, a collision between cranes on site and evaluation of jobsite scenarios, the participants' preference for the use of 3D models is significantly greater than for the option of using a 2D model. On the other hand, between the ordinary 3D model and 3D model by use of VR technology, the participants' predisposition towards the use of 3D models in VR is slightly higher. Moreover, respondents believe that the 2D model is easier to use for jobsite organisation layout and 3D-VR technology is the most complex option. This necessitates the need for training the novice VR-technology users to mitigate the use of less effective but habitual use of 2D models.

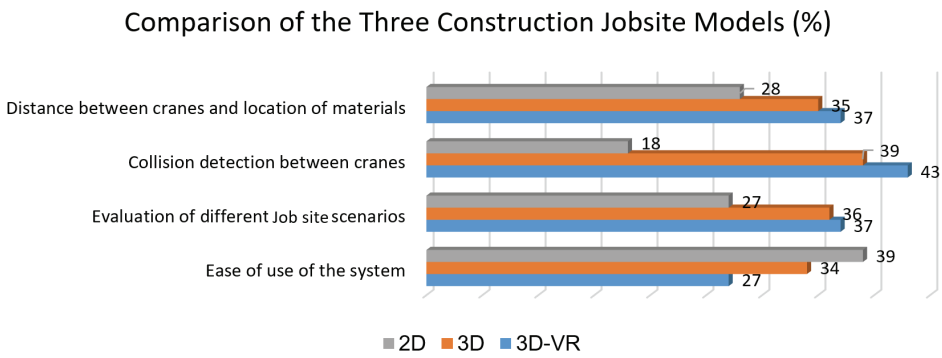

Figure 12 - Comparison of the Three Construction Jobsite Models by Industry Professionals

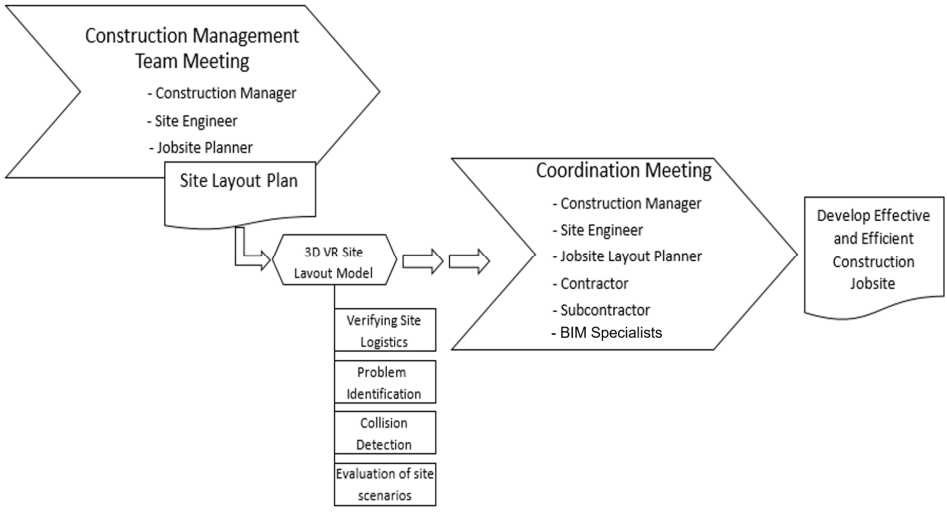

Figure 13 - Proposed Process Flow for Managerial Applications of VR Technology in Construction Jobsite Organisation

5. CONCLUSION AND FUTURE WORK

Construction managers have the key responsibility to manage and allocate individuals for appropriate roles in construction projects. Construction managers (CMs) hold the authority to hire and organise individuals such as site engineers, plant managers, foremen, and labour crews and it is the responsibility of CMs to assign duties to these individuals. Moreover, creating an effective work environment by producing a competent jobsite layout plan is among the critical duties of planners and site engineers. For that reason, whilst allocating individuals with duties, CMs should provide the site engineer and jobsite planners with relevant information on how to improve productivity and safety within the worksite so that it can be reflected on the layout plan. In the proposed process flow given in Figure 13, it is

recommended that the final 3D CAD site layout plan model developed by the site engineers and site planners is visualised by a focus group led by the CM using immersive or desktop VR technology. By visualising the model, underlying information of the jobsite organisational plan is believed to be perceived. The visualisation of the jobsite layout plan aids to verify site logistics, problem identification, collision detection, and evaluation of site scenarios in a situation where more than one site scenario is generated. On the other hand, it is essential to schedule a meeting for the related parties so that parties involved in the meeting communicate about matters concerning the establishment of each specific jobsite layout plan. By doing so, problems can be mitigated before the establishment of the actual construction site. Hence, an effective work environment can be developed.

This study seeks to explore the applicability of VR technology for construction jobsite organisation. For this purpose, the comparison between the traditional methods used in construction jobsite organisation and 3D site planning via adopting a VR headset is performed. Within this framework, the ability of VR technology for jobsite layout organisation is explored. The findings reached in this study are based on both direct observations of the participants of the 3D VR site plan models (screenshots obtained from the VR headset) and analyses of participants' questionnaire survey results. At the end of the comparison, the authors of this study discovered that traditional 2D methods used in site layout planning are less time-consuming and easier to understand compared to the VR-based 3D site plans. This could be for a range of reasons, such as inexperienced users and the complexity of different headsets. On the other hand, participants' responses indicate that the ability of the site plans in assisting users to comprehend and evaluate different jobsite scenarios as well as collision detection ability is more effective if a 3D site plan in VR technology is adopted instead of the 2D and 3D site models. Also, participants stated that the assessment of the system is a bit slower, but it enables anticipation of the reality of the site conditions and restrictions. It is recommended for construction managers to practice 3D CAD visualisation technology as it is beneficial to determine how the construction jobsite is being organised. As discussed above, it is to the advantage of jobsite planners to make use of the proposed visualisation technology in other to improve the efficiency of the construction jobsite organisation tasks. This visualisation technology can help construction managers and jobsite planners to visualise the arrangement of jobsites, thus providing them with a more detailed illustration of the site plans and enable them to visualise the amount of space available on site. By visually observing the space utilisation, one can develop a better construction site utilisation plan.

The body of results shows the applicability of the framework for a variety of engineering scenarios, problem-solving, and improving the performance of projects especially for site layout planning. Future directions of work include testing different available types of VR technologies at the market for site layout planning with presented framework. We will also investigate the benefits of this framework in different international construction projects to identify strengths and weaknesses to improve the overall performance of that.

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