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SUSTAINABLE CONSTRUCTION RISK ASSESSMENT THROUGH DYNAMIC SITE LAYOUT PLANNING AND SIMULATION BY BUILDING INFORMATION MODELLING

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Abstract- Construction industry is prone to risks due to the dynamic nature of activities and the placement of numerous facilities at site. Mostly, site layouts are treated as static, whereas, construction projects are dynamic in nature, whose requirements change over time. With the growing concern for sustainable development in construction sector, it is imperative that risks at construction projects related to all aspects of sustainability; social, economic and environmental must be evaluated. Therefore, dynamic site layout planning integrating sustainability risks was performed in this study. A model considering the interaction flows between construction facilities and their safety/environmental concerns was employed to assess the safety risks for the sustainable site layout planning. A case study of a commercial building project of developing country was selected to validate the safety risk assessment model. The interaction flows between facilities and their safety/environmental concerns were evaluated and risk of site layout was calculated for the case study. The risk assessment model was then optimized by varying the interaction flows for all phases of project and a new site layout scenario was developed with reduced risks. Sustainability risks arising due to various facilities were evaluated from their interaction flows and safety/environmental concerns. Building Information Modeling (BIM) was used to develop the dynamic site layout scenarios. By dynamic site layout planning risky nature of construction site was reduced by 26.47% and social, economic and environmental risks are reduced by 25.43%, 18.31% and 17.71% respectively. This model is valid for a variety of construction and infrastructure development projects and can be used by various stakeholders of the construction industry for sustainable site layout planning.

Keywords- Building Information Modeling, Construction Safety, Construction Site Layout Planning, Sustainability Risks Assessment

1. INTRODUCTION

Construction site layout planning is one of the most overlooked aspects at construction projects and is subject to the decision of the project manager [1]. The facilities are usually allocated at the site on first come basis without giving any consideration to the associated hazards and risks. Failure to plan the site layout creates conflicts at site which leads to operational inefficiency, increasing the safety risks and the overall cost of a project substantially [2]. In construction projects, site space is a precious asset that should be meticulously and productively designed. Construction site layout planning requires identifying site facilities, defining their size and allocating location for these facilities on site [3]. The temporary facilities include heavy equipment and machinery, material and components storage areas, operation plants, site accessories and residence areas [4]. As the project progresses, more number of facilities are added in the site increasing the complexity of layout and thus more constraints to look for. In addition, as construction evolves, the site layout may need to be dynamically reorganized at various schedule intervals to accommodate the operational needs. The complexity of site layout planning can be dealt with Building Information Modeling (BIM) tools [5, 6]. BIM has been perceived as an advance tool which has revolutionized the construction industry. BIM can be used to provide users with a safe site layout plan by its dynamic planning and 4D simulation features. This is vital to ensure the safety of the working environment and for efficient operations. BIM is a tool that represents physical characteristics as well as functional abilities of a facility. BIM model is data rich, item oriented, intellectual and parametric illustration of facility after that views as well as data fitting to numerous users' desires can be gained and then analysis can be done to produce evidence that are used to mark results and increase workability. The utilization of BIM for facilities layout planning is a relatively new practice of BIM.

Many of the project delays, cost overruns and fatalities are due to the improper site layout planning. These risks are social, economic and environmental in nature. Social risks are related to labor disputes and strikes, labor productivity and defective work, theft and vandalism, epidemic illness and accidents affecting the health and well-being of construction workers. Economic risks are due to the increased transportation costs of materials within site, warehouse fee, set-up and dismantling cost of facilities, price inflation of construction materials, incomplete or imprecise cost estimate, etc. Environmental risks are concerned with pollution as a result of construction activities (level of noise, dust, excessive vibrations, potential energy, and site wastes), adverse weather conditions, and force majeure [7-9]. A safety risk assessment was performed by Ning et al. [10] on a construction project with 16 facilities in total. The site layout was planned and 3 scenarios were developed. The safety risks were calculated for the temporary facilities and all the locations that are still unoccupied within the site boundary. The total safety risk level of site layout for the scenario 2 (80.99) was found to be the least as compared to scenario 1 and scenario 3. This shows that construction projects with various facilities have a huge untapped potential to reduce the safety risks by proper planning of the site layout. This can also have huge implications for reducing the social, economic and environmental risks related to site. Site layout planning is not limited to construction sites only, it can be applied to manufacturing and production facilities as well. Dynamic layout planning was implemented on case study of steel fabrication industry and benefit in terms of reduction in haulage time was observed [11].

The aim of this work is to formulate a dynamic site layout plan, in order to minimize safety and sustainability risks. This is achieved by devising a safe construction site layout plan by quantifying the risks associated with construction facilities. The work identifies the temporary facilities required at each project phase, determining facilities' required characteristics (size, shape, orientation, etc.). The project is divided into phases and site layout planning is treated as a dynamic activity. The solution is developed considering the placement of facilities at various locations by manipulating their distance, interaction flows and safety/environmental concerns. This is done by taking into account the changes in construction schedule to avoid any relocation during project timeline. The work is validated through a case study project with an existing site layout and a modified site layout with reduced risks. Then, sustainability risks are calculated by manipulating the distance between facilities that can pose social, economic and environmental risks.

2. RESEARCH METHODOLOGY

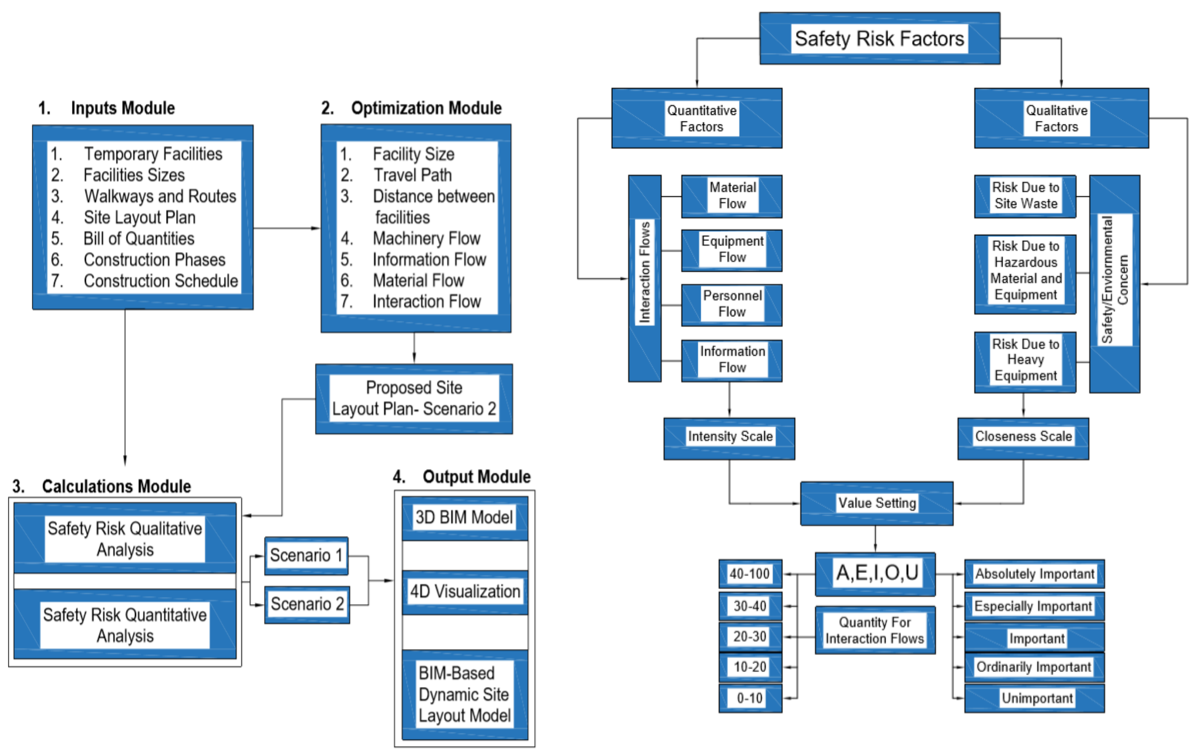
In the process of assessment of safety risk factors, the relevant literature was reviewed and the temporary facilities at construction sites were reviewed. As an input the interaction flows and safety/environmental factors were assessed for each facility. Site layout scenarios were developed before and after the risk assessment process. The working methodology of this work is given in Figure 1 (a).

2.1 Construction safety risk factors analysis scale.

The safety risk factors are either taken as quantitative or qualitative as defined by Ning et al. [10]. The quantitative risk factors are the interaction flows between facilities, as there is a constant flow of materials, labour, equipment and information between the facilities. The risks which arise due to; waste at site (excessive noise, dust, vibrations, energy, temperature); hazardous materials (explosives, chemicals, inflammable materials, fuel, high voltage) and any hazardous equipment; and the risks due to the presence of heavy equipment (tower crane, material hoists) are taken as qualitative risks. An intensity scale consisting of five ranks is used to measure the quantitative risk factors. A closeness scale of five ranks: A (absolutely important), E (especially important), I (important), O (ordinarily important) and U (unimportant) which is decided by the project manager at site is used to measure the qualitative risks and is defined in Figure 1 (b). A construction site consists of occupied locations by temporary facilities, unoccupied locations and any buildings which are already existing at site. The total safety risk level of the construction site should consider the occupied locations by temporary facilities and unoccupied locations for future placement of facilities. Dangerous facilities such as tower crane, material hoist and workshops around unoccupied locations pose a risk to them. The location of temporary facilities is greatly influenced by the presence of dangerous facilities around them and the intensity of various flows termed as interaction flows between these facilities. So, the total safety risk level of the site layout plan is calculated in terms of the interaction flows due to material, equipment, personnel and information; and the various safety/environmental concerns. Assessment functions are used to calculate the total safety risk level of the site layout plan.

2.2 Safety risk level considering interaction flows and safety/environmental concerns.

If the materials are frequently transported between facilities, and there is a frequent movement of equipment and labor (personnel) between the facilities with scarce communication; it results in an increased probability of accidents. Also, longer distances between facilities resulting in longer travel routes create more intersection points that lead to increased number of accidents. Distances between the temporary facilities affect the safety risk level so these distances are measured between each concerned facility as Euclidean distance. Risks that arise due to any site waste (noise, pollution, etc.), hazardous materials-and-equipment and heavy equipment affect the workers' health and safety on construction site. The falling objects from heavy equipment such as tower crane and material hoist represent potential hazards. So, there should be specific location for these equipment to minimize the construction site risk. Quantitative and qualitative risks are calculated for each facility in each phase and their summation gives the total safety risks of construction site layout. The social, economic and environmental risks are also evaluated by the relevant interaction flows and safety/environmental concerns of the facilities in each phase for scenario 1 and 2. The facilities interaction flows are manipulated to reduce the safety concerns due to the presence of dangerous facilities. The equations used to calculate the risks due to interaction flows and risks due to safety/environmental concerns are utilized from the work of Ning et al. [10].



a) b)

Figure 1 a) Working methodology b) Safety risk factors scale

3. CASE STUDY.

A case study of a live project is selected to verify the risk assessment method that enables the site managers to assess diverse site design situations and pick the best one with least safety risk level. Two different site layout scenarios are taken of a 14 story (2 basements, ground plus eleven typical floors) mixed-use building located in Lahore, Pakistan. The DCSLP is done for this case study by dividing the project duration into four phases on the basis of material requirements, equipment usage and changes in facilities arrangement at site. Then two site layouts (scenario 1 as shown in Figure 2 (a) and scenario

2 as shown in Figure 2 (b)) are developed and the site layout for the last phase (phase 4) is shown in Figure 2. First scenario is the existing site layout of the project (as decided by the project manager) and second scenario is the proposed site layout for the same site. In existing site layout, transportation routes and walkways are not defined between temporary facilities. Distances between temporary facilities are longer due to which the probability of collision and collapse increases that results in severe accidents and fatalities. The interaction flows between facilities are also greater that increases the likelihood of hazards. In proposed site layout proper routes and walkways are defined with safety zones. Distances and interaction flows between facilities are decreased that reduces the safety risk level and enhance the safety level. Also, the quantity of tower cranes has been reduced to 2 (as shown in Figure 2 (b)) instead of 3 (as shown in Figure 2 (a)) that will minimize the cost for heavy equipment and will also reduce the hazard of falling objects. The dynamic modelling of both site layout scenarios is done in Revit as shown in Figure 3 and the simulation is performed in Navisworks. The facilities involved in the various phases of the project and used to plan the site layout are listed in Table 1.

Table 1 List of temporary facilities at case study project

Facility	**Code**	**Size (m^2)**	**Facility**	**Code**	**Size (m^2)**	**Facility**	**Code**	**Size (m^2)**
Tower Crane # 1	F1	4	Rebar Bending Workshop	F7	120	Brick Yard	F13	112
Tower Crane # 2	F2	4	Testing Lab	F8	28	Gravel Yard (Sand)	F14	160
Tower Crane # 3	F3	4	Fuel Storage Area	F9	27	Gravel Yard (Crush)	F15	400
Material Hoist # 1	F4	7	Formwork Area-1	F10	410	Cement Yard	F16	110
Material Hoist # 2	F5	7	Formwork Area-2	F11	222	Batching Plant	F17	95
Steel Yard	F6	225	Shuttering pipes	F12	270	Steel Raw Material	F18	150

a) b)

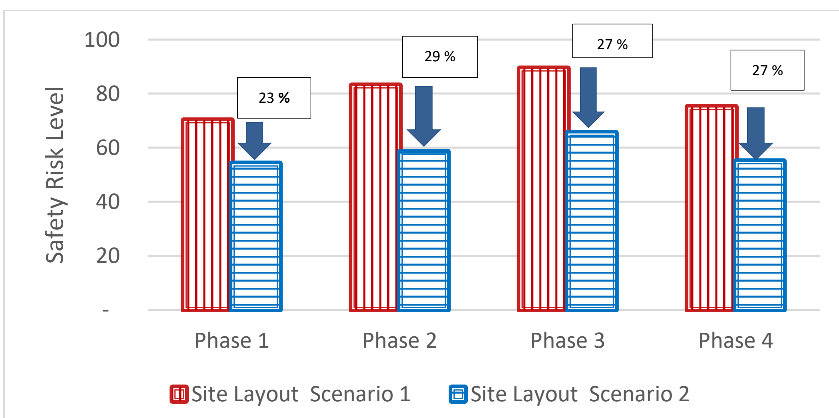
Figure 2 Construction site layout of phase 4 for a) Scenario 1 b) Scenario 2

4. RESULTS

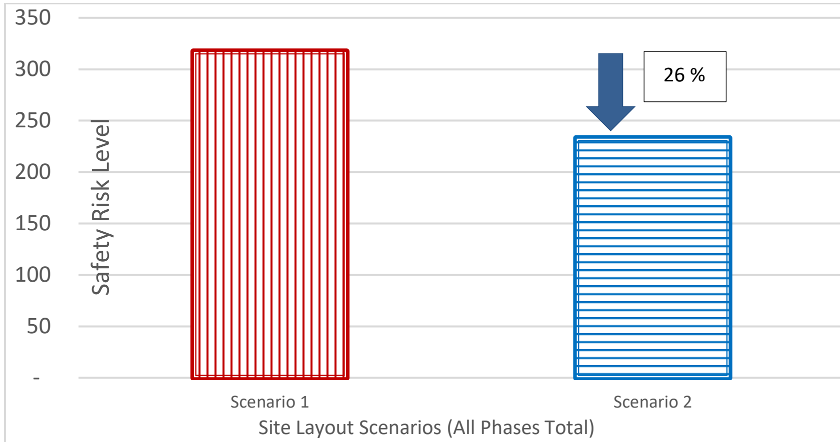
4.1 Risk assessment.

The safety risk level due to the presence of all the temporary facilities, unoccupied locations and site for four construction phases based on interaction flows and safety/environmental concerns is performed. A comparison of safety risk level is presented in Figure 4 (a) for each of the four phases of the project. The safety risk level has reduced from 23% for phase 1 to a maximum reduction of 29% for phase 2 in case of scenario 2. The maximum reduction in safety layout of 29% in phase 2 of the project is due to the presence of maximum number of facilities in that phase which provided an opportunity to the projected manager to effectively plan the facilities layout and thus reduce the many risks in that phase. The total safety risk level of site layout for the whole project (complete project lifecycle) in the site layout scenario 2 has lower value (233.09) than scenario 1 (317.34) due to proper planning of facilities location and position and effective utilization of unoccupied locations from previous phase in the next phase of the project, as shown in Figure 4 (b). The value of safety risk level of temporary facilities at construction site due to the various flows between facilities and safety/environmental concerns are 172.70 and 60.39 respectively for total four construction phases of scenario 2 which is lower than that of scenario 1 as 230.9 and 86.44 respectively. A maximum reduction of 25% is observed in the social parameter of sustainability risks. This is due to the fact that separate paths of vehicles are designed to reduce accidents due to collision, marking of safety zones (personal protective equipment-PPE zones and partial PPE zones) throughout the construction site and increasing the distance between dangerous facilities. It is observed that the sustainability risks values are lower for scenario 2 as compared to scenario 1 as shown in Figure 4 (c). Scenario 2 (after site layout planning) has the greater safety level than scenario 1 (before the site layout planning). Therefore, scenario 2 is the preferred site layout for the stakeholders of the construction project and the decision-makers on site.

Figure 3 BIM model of construction site layout Scenario 2



a)



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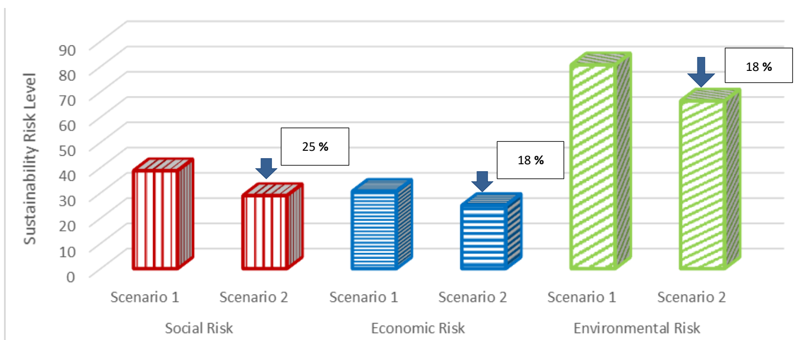

c)

Figure 4 Safety and Sustainability risk level of site layout scenarios (a) safety risk level of phases, (b) total safety risk level and (c) social, economic and environmental risk level

4.2 Site layout modelling and simulation

BIM solutions include many attributes which offer several interesting opportunities to promote safety at construction sites. The visualization offers a totally new tool for risk assessment, planning, introduction, safety management etc. Additionally, 4D-BIM means improved chances to make alternative preliminary plans of different construction stages and tasks. In order to make the dynamic site layout, 3D model was created in Autodesk Revit for both scenarios. The structural model is on Level of detail (LOD) 300. A number of parametric and non-parametric components library was developed to achieve the desired LOD. Firstly, the information about project tasks was imported from schedule from the project planning software application. Then, linked elements in the composite model with tasks in the schedule. Finally, the schedule was simulated for all phases of project through timeliner of Navisworks.

5. APPLICATION IN FIELD

The construction industry is subjected to risks of varied nature on account of the presence of various hazards on site. These hazards are due to the use of equipment, machinery, vehicles and other facilities at site. These facilities if not properly planned and managed during the life of the project can lead to incidents and accidents that can incur huge financial and health related losses. Through dynamic site layout planning, the project managers can effectively and efficiently plan and manage various facilities at site. The site can be managed at each project phase to accommodate new and upcoming facilities without affecting the productivity of operations. The risks associated with facilities location, position and logistics can be identified beforehand and effective measures can be put in place to reduce these risks. The risks related to social, economic and environment can be evaluated for further mitigation. Planning the site layout of construction projects thus, has huge benefits for all the stakeholders of the construction industry to reduce additional site layout costs, improve productivity of labor and operations by reducing hazards and risks.

6. CONCLUSION

This paper reveals the importance of dynamic site layout planning to reduce safety and sustainability risks during the construction phases of project. The risk assessment integrating the various interaction flows and safety/environmental concerns of temporary facilities can be performed to evaluate safety and sustainability risks. This can help the project managers to evaluate construction site layouts and select the layout with minimum risk level. The working in this paper can be utilized to systematically and scientifically evaluate the safety and sustainability risks at each construction phase to come up with a site layout that has total minimum risks. Proposed layout (Scenario 2) is the optimized solution to safety issues as the safety risk level is reduced by about 26.47% as compared with scenario 1. This paper contributes in identifying and classifying risks related to construction site facilities. Sustainable construction site risks are also reduced by optimization of site layout including social risk (25.43%), economic risk (18.31%) and environmental risk (17.71%).The results obtained suggest that to reduce the safety risk level of construction site, the project managers are inclined to decrease the frequency of movement of materials, equipment and personnel between facilities; and minimize the distance between facilities. Temporary facilities which have greater flow of material, equipment and personnel between them should be placed close to each other to avoid any conflicts in operations. Dangerous facilities and heavy equipment should be located at far off distances from the temporary facilities specially residence facilities as the hazard decreases with distance. Also, special safety zones (personal protective equipment-PPE zones) should be developed around heavy equipment to reduce risks due to falling objects. Taking this study further, the future research can emphasize on the automated ruled based checking using BIM technology integrated with virtual reality for better and safe site layout planning and real time visualization of safety hazards.

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REFERENCES

[1] I. N. Papadaki and A. P. Chassiakos, "Multi-objective Construction Site Layout Planning Using Genetic Algorithms," *Procedia Engineering,* vol. 164, pp. 20-27, 2016/01/01/ 2016.
[2] K. Li, H. Luo, and M. J. Skibniewski, "A non-centralized adaptive method for dynamic planning of construction components storage areas," *Advanced Engineering Informatics,* vol. 39, pp. 80-94, 2019/01/01/ 2019.
[3] I. Abotaleb, K. Nassar, and O. Hosny, "Layout optimization of construction site facilities with dynamic freeform geometric representations," *Automation in Construction,* vol. 66, pp. 15-28, 2016/06/01/ 2016.
[4] X. Song, J. Xu, C. Shen, and F. Peña-Mora, "Conflict resolution-motivated strategy towards integrated construction site layout and material logistics planning: A bi-stakeholder perspective," *Automation in Construction,* vol. 87, pp. 138-157, 2018/03/01/ 2018.
[5] R. Bortolini, C. T. Formoso, and D. D. Viana, "Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling," *Automation in Construction,* vol. 98, pp. 248-264, 2019/02/01/ 2019.
[6] S. S. Kumar and J. C. P. Cheng, "A BIM-based automated site layout planning framework for congested construction sites," *Automation in Construction,* vol. 59, pp. 24-37, 2015/11/01/ 2015.
[7] X. Ning, J. Qi, C. Wu, and W. Wang, "Reducing noise pollution by planning construction site layout via a multi-objective optimization model," *Journal of Cleaner Production,* vol. 222, pp. 218-230, 2019.
[8] J. Hong, T. Hong, H. Kang, and M. Lee, "A Framework for Reducing Dust Emissions and Energy Consumption on Construction Sites," *Energy Procedia,* vol. 158, pp. 5092-5096, 2019/02/01/ 2019.
[9] M. Andayesh and F. Sadeghpour, "Dynamic site layout planning through minimization of total potential energy," *Automation in Construction,* vol. 31, pp. 92-102, 2013/05/01/ 2013.
[10] X. Ning, J. Qi, and C. Wu, "A quantitative safety risk assessment model for construction site layout planning," *Safety Science,* vol. 104, pp. 246-259, 2018/04/01/ 2018.
[11] P. Alanjari, S. RazaviAlavi, and S. AbouRizk, "Hybrid genetic algorithm-simulation optimization method for proactively planning layout of material yard laydown," *Journal of Construction Engineering and Management,* vol. 141, no. 10, p. 06015001, 2015.