Review of Construction Workspace Definition and Case Studies

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Abstract -

Workspaces in a construction project are considered as critical and limited resources. Since the workspace conflicts cause productivity loss and poor quality, construction researchers have been exploring different workspace definitions and solutions to improve the situations. Construction workspace' function can be classified according to the user's needs and characteristics of activities and can be integrated into 4D BIM simulation. In previous studies, researchers have proposed several different and innovative workspace definition. However, researchers usually only tested their proposed workspace definitions on specific building projects or few particular tasks. It is difficult to tell the effectiveness of the workspace definition when applying to a different construction project or case involving different construction methods. Relevant works of literature regarding construction workspace definitions were collected and discussed in this article to obtain a comprehensive review on this topic. We have applied the proposed definition to the same construction case and also provided an evaluation of their approaches' pros and cons. Then we proposed a criterion of developing proper workspace, so the workspace requirement can be planned based on the project's characteristics and could help the project managers to select the optimum scenario during workspace planning.

Keywords -

Workspace Conflict; Workspace Classification; Conflict Solution; 4D BIM; Conflict Severity

1 Introduction

Various subcontractors have to finish working activities in a space-limited construction site. Each activity requires a certain amount of workspace for workers, equipment areas, etc. Workspace conflicts between activities could result in schedule delays and poor quality. Since there is a rising demand for complicated construction works in the municipal area, the need for a proper construction site layout is crucial to eliminate workspace conflict.

However, it is challenging for the project managers to eliminate the interference caused by workspace conflicts among activities because traditional 2D drawings are not enough to indicate dynamic changes and enough information of equipment's and labors in the construction site.

Therefore, many researchers took efforts to develop techniques such as building information modeling (BIM). The 4D BIM models with schedule management in recent years has been broadly utilized among buildings' life cycle. Researchers also tried to strengthen the techniques of workspace conflict analysis and tried to find better solutions. The studies in the past 20 years covered methods of how to identify the workspace requirement of each activity, how to develop and detect workspace conflict, how to solve the problem before the construction phase starts, and how to simulate dynamic workspace conflict due to dynamic changes.

Since theories of workspace conflict analysis have been evolved for more than 20 years, definitions of workspace has been very different in different studies. While each of these theories of workspace definition can explain some aspects of construction projects, none can successfully be applied to all instances of construction projects. Rather than pursue this further by finding the best definition for all construction projects, we will explore a criterion to select proper definition for workspace conflict analysis by studying and summarizing previous studies from a detailed review covering the different workspace definitions.

2 Literature Review

In this study, we collected previous studies regarding workspace conflict analysis from 2002 to 2018. Table 1 shows a summary of the most important publications in this field and the different factors focusing on by researchers. We will discuss each factor in detail in the following session.

Table 1. Comparison of Previous Workspace Conflict Studies

Reference	Workspace Requirements Definition	Workspace Occupation Representation	Workspace Conflict Detection	Conflict Severity Index	Conflict Severity Quantification	Conflict Solution Strategy
[1]	*	*	*	*		*
[2]	*	*	*	*		
[3]	*	*	*	*		*
[4]	*	*	*			*
[5]		*	*			
[6]	*	*	*	*		*
[7]		*	*	*	*	*

2.1 Workspace Definitions

Workspace definitions are broadly discussed and classified by researchers. Thabet and Beliveau [1] have classified the space into two groups, one is man and equipment, and the other is materials. These two groups are classified according to whether the size of space will be constant or decreased by time. This classification will help to provide the evaluation of the activity's space demand by the sum of quantities from each factors' physical needs and surroundings' needs.

Akinci, Fischer [2] classified construction activities into three categories based on reference object, orientation, and parameters. The categories included macrolevel, microlevel, and paths. Macrolevel spaces referred to huge-scale, such as storage or prefabrication areas. Microlevel spaces were mostly related to building components, and paths were required for transportation. Guo [3] has classified the spaces based on different four users: labor, equipment, materials, temporary facility. Considering whether the space is available for work or not, the space needed for each user could also be defined by space type as the exterior of the job site, the interior of the job site, inside the structure, and space provided by a temporary structure.

Choi, Lee [4] separated the workspace layout by its function or movability. When by function, it includes direct workspace (object space, working space, and storage space); indirect workspace includes set up space, path space, and unavailable space. When workspace defined by movability, it can be separated into fixed workspaces and flexible workspaces. The purpose of classification by function is to stand for total workspace definition without missing; moreover, classification by movability is to supply a resolution of workspace conflict after it has been identified.

To deal with dynamic nature in construction sites, Su and Cai [5] proposed two ways of defining workspace: 1) workspace directly created by users, and 2) workspace created based on geometric shapes such as column, sphere, tetrahedron or hexahedron. The latter is based on the simulation of labor workspace or tower crane workspace and provides users to derive workspace with two functions: offset and rotate.

However, the construction layout may be changed by schedule. Dynamic changes based on time flow in a construction site also need to be considered in the use of workspace[2, 6, 7].

Tommelein and Zouein [6] tried to connect the construction layout plan and project schedule plan, which consider the dynamic changes of location and activities in the construction site. Kassem, Dawood [8] suggested providing the definition based on whether the physical change on the construction site was added or not in 4D BIM model. They also defined the object workspace, which represented building elements, and safety workspace that is tolerance between two workspaces, or the distance which objects may fall from height.

Mirzaei, Nasirzadeh [9] defined the varied nature of activities, considering space should be static when the labor crew occupies a place thoroughly during the whole activity duration. Dynamic workspace, on the other hand, represents that the labor crew will move their space during each time interval.

Table 2 shows the collection of workspace definitions from previous studies.

Table 2. Summary of Workspace Definitions

	Definition	Authors
By constant level	Man and Equipment	[1]
By decrease level	Materials	
By users	Labor	[3]
	Equipment	
	Materials	
	Temporary Facility	
By availability	The exterior of Job site	
	Interior of Job site	
	Inside the Structure	
	Space provided by Temporary facility	
By scale	Macrolevel	[2]
	Microlevel	
By function	Direct Workspace	[4]
	Indirect Workspace	

By movability	Fixed Workspace	
	Flexible Workspace	
By geometric shape	Column	[5]
	Sphere	
	Tetrahedron	
By physical change or not	Main Workspace	[8]
	Support Workspace	
By building elements	Object Workspace	
By safety distance	Safety Workspace	
By position changed of labor crew	Dynamic Workspace	[9]
	Static Workspace	

Since there is a variety of workspaces definition, it is crucial to set a flow chart for construction site layout that is useful for specific needs. In the following paragraphs, we will discuss three workspace characteristics proposed by Akinci, Fischer [2], which are generality, reusability, and comprehensiveness.

Generality means we can apply for various workspace requirement, especially for spaces which are related to building components, such as equipment and crews. However, storage areas for materials are also important that should not be ignored. Since some materials are temporary and are waiting to be installed in buildings, but some materials will be left for owners as a backup in the maintenance stage, it is important to set a clear layout easy to separate temporary and permanent materials.

Reusability means construction activity is repeatable or can be done by the same equipment no matter what locations or sizes they have. Usually, Since the construction methods depend on the location and some specific constraints, there will not 100% the same in each location. For example, if there is a window at 20 floors high rise building, but the space beneath the window is not large enough to locate a crane , then the construction method had to changed based on constraints. However, it is too hard to expect what will happen during construction. So, it will be suitable for site managers to follow the most common construction methods for construction.

Comprehensiveness is about the details when it comes to describing the construction methods. The orientation and the volume (length, width, height) of a required workspace should be seen or modified. Each equipment would have its maximum range of workspace. For example, the crane's range can be calculated by the radius chart.

As we've mentioned, these 3 factors are crucial to represent a construction site. In addition, we still notice that it is hard to define the best layout for the construction site, but we can discuss this problem consider the scale.

The case in Guo's research is a 12-story reinforced concrete, and the case in Akinci's research is about the installation of windows in a wall. Since 12-story reinforced concrete is a huge project, so he first classified by major activities survey, reinforced steel, plumb…etc.), then each major activity requires 4 main categories (labor, equipment, materials and set-up space). However, a small construction site is no needed for such a detailed workspace definition. On the other hand, if the layout classification is too simple, some places could be neglected and may become a potential problem. So, it is much proper to define the scope of a construction site in a simpler way first, then give a more detailed classification if necessary.

2.2 Virtual Spatial Collisions

After the workspace definition is decided, workspace for each activity is created for spatial collisions.

According to a 3D bounding volume, three types of space collision detection algorithm can be used in a 3D model, which are bounding spheres (BS), axis-aligned bounding boxes (AABB), and oriented bounding boxes (OBB). The method of bounding spheres is to detect the collision by detecting the sum of two bounding sphere's radius and also the distance between the center of two spheres [10]. Oriented bounding boxes were introduced by Möller and Haines [11], which created minimum bounding boxes around objects without considering the object's axis, and the existence of another axis identified the collision. Axis-aligned bounding boxes need to determine the minimum and maximum coordinate values of the two bounding boxes, which are parallel to their coordinate axes. Figure 1 illustrates three types of collision detection described above.

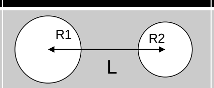
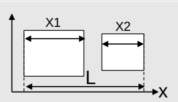
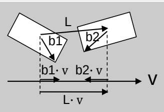
	Diagram	Collision Condition
Bounding Sphere		$L<R1+R2$
Axis-Aligned Bounding Box		$L < X1+X2$
Oriented Bounding Box		$\lvert L \cdot v \rvert < \lvert b1 \cdot v + b2 \cdot v \rvert$

Figure 1. Collision conditions

When it comes to the application, axis-aligned bounding boxes (AABB) are used most common on building objects such as beams and columns, most of their shapes are rectangular cuboid. Bounding spheres (BS) methods for workspace conflicts are suitable when there are multiple crane works. But these methods can be combined for specific cases, too. In the installation process of prefabricated steel beams working area, crane work may also affect the installation of the bolt works.

2.3 Moveable Objects

Since the construction site is dynamically changed with schedule, it is critical to detect the resource movement. Previous studies usually assumed that the laborers occupied the whole workspace throughout its duration. However, labors only occupy a part of the needed workspace and change their location all the time. The dynamics of activities should be investigated, and also the patterns of where they start, execute, and end. Few studies have addressed the significance of the activities transition in a required workspace. Mallasi [12] developed 12 execution patterns. Choi, Lee [4] presented the concept of unrealistic workspace problems in Figure 2 which may exist in two activities.

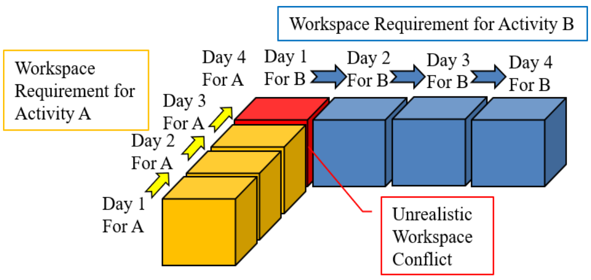


Figure 2. Unrealistic workspace problem modified [4]

The most significant assumption about the construction layout is static. But dynamic changes of the workspace by schedule are also essential when the activities can not be done in a day. If the construction site can be divided into different small spaces, then it will be crucial. This will help when your activity has overlapped other nearby activities' workspace. If both conflict activities can not change each sequence or schedule, then it will be easier to adjust the working sequence and to avoid unrealistic problems.

2.4 Index of Conflict Severity:

The measurements of workspace-conflict need to be qualitative and quantitative.Akinci, Fischen [13] suggested a conflict ratio, which is the ratio between the conflict volume and the required space volume. Guo [3] used the interference space percentage (ISP) and the interference duration percentage (IDP) as two indicators. One is the ratio between the interference space size and the activity's original size, and the other is the ratio between the interference duration and the activity's original duration. Mallasi [12] created a five-criteria quantification index to identify the conflicts. Kassem, Dawood [8] took the congestion severity (CgS %) as the ratio of the sum of the required space and the available space.

The concept of conflict severity can be assessed. However, this indicator cannot quantify the impact of conflicts on project performance. Mirzaei, Nasirzadeh [9] define a new approach to calculate the conflict severity by the labor congestion and conflict space size

Figure 3 shows the different definitions of the conflict severity index.

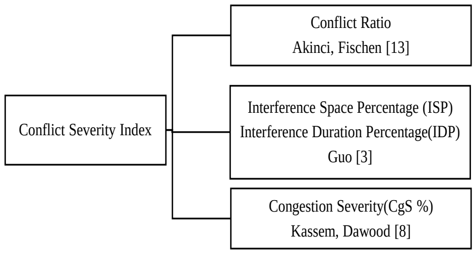


Figure 3. Conflict severity index

In previous studies, several solutions have been derived, but the relationship between the conflict severity and resolution need to be discussed. The goal of conflict severity is to help managers decide the best solution. However, a single number can not reflect the total situation in each study, which may cause the manager hard to decide the best solution. Although in Guo [3] study, ISP and IDP can be calculated and criteria for resolving space conflict are suggested, but there is little discussion on the relationships between these two indicators.

Some studies have suggested congestion as another conflict severity, which is the ratio between the available workspace per person and the minimum workspace required per person.

2.5 Solution For Workspace Conflict

The solution of workspace conflict is crucial since it could help the project managers to raise the working efficiency. Guo [3] not only suggested to change the logical sequence, location, or starting time for conflicting activities to avoid problems but also suggested to recheck the path demand after changing. In a study from Choi, Lee [4], they proposed to change the location of flexible workspace or consider both the schedule plan for critical and non-critical activities. Kassem, Dawood [8] suggested 2 solutions, first is changing and adjusting the schedule, second is changing and adjusting the physical location and size of workspace.

3 Discussion

The aim of this research was to review previous studies on workspace definitions and conflicts resolutions. Some other factors should be considered and further discussed since there would be some relations between workspace definitions and other factors when conducting conflict analysis.

3.1 4D BIM Applications

Compare to 2D drawing, 4D BIM provides diverse information and visual environment, which can help managers to arrange a proper workspace in the 4D model on a whole scale of the construction site. Most of the previous researches had considered using BIM application programming interface (API) for workspace planning, and this study might help technologists and project managers to follow a criterion for workspace planning by applying BIM API.

3.2 Case studies

Each previous research will choose a case study as their theory's implementation. Now we select the case study in Automated Generation of WorkSpaces Required by Construction Activities by Akinci, Fischer [14], which is about using scissor lift for windows installation.

Figure 4 shows the background of this project. We applied and compared several workspace definitions in the following paragraphs.

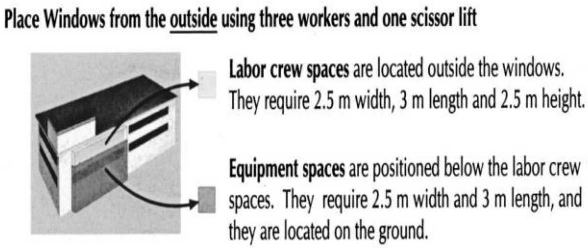


Figure 4. Windows Installation Information [14]

● By scale : This advantage is that we can have a rough range of space sizes for workspace management. Project managers can focus on microlevel spaces, which are the components (windows), equipment(scissor lift), and labors. Its definition seems a little hard and vague to classify whether the items should belong to the macrolevel or microlevel.

● By location: This classification consider whether its the space is exterior or interior of structure/jobsite. However, this does not necessarily needed for a small project since the working and storage area are easy to arrange. It will help if the project's scale is big and the time is long enough so that managers can control all the items in detail.

● By function: The advantage of this definition is that this will help the managers focus more on whether the condition for each workspace is prepared or not to function, rather than to use location or size level as classification.

● By movability: The disadvantage is that this classification may not be so necessary for a small construction project.

● By position changed of labor crew:This can show a dynamic motion for labor workspace by schedule. The feature of this classification is that if the works can not be done in a day, managers can easily understand the work sequence in the schedule. However, if there is no conflict with other activities workspace, then this works sequence seems a little unnecessary.

In this case, we can form up a guideline for planing a proper workspace layout for different kinds of construction sites. Figure 5 shows the workspaces planning into four levels:

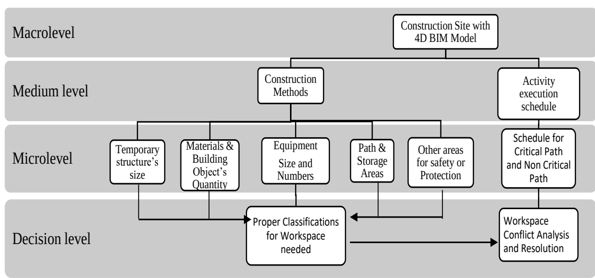


Figure 5. Workspace layout planning flow chart

Macro-level is about choosing types of construction sites, which may be buildings, factories, roads, or other related constructions. The medium level begins to select the construction methods for each activity. Microlevel would let the project manager select necessary and detailed elements to create a proper workspace layout planning in the decision level.

4 Conclusion

This study reviewed the previous research of workspace definitions and conflict resolution. From the literature review, there are different types of workspace definitions based on several aspects. We also investigate these theories and apply them to a case study. The discussion showed some results that include the pros and cons of whether these factors are necessary for workspace planning. There is no standard answer for classification since each project is unique, a workspace planning flow chart can be helpful to establish a workspace layout with construction methods and quantities of each activities.A proper workspace classification still relies on the degree of understanding among project managers.

However, our study ignores the time-schedule factor, which is a limitation that may somehow affect the result of classification. Future work can focus more on the workspace conflicts of activities in period of time which can discuss a more specific workspace conflict.

Another future research can be further discussed since people can rely more on the development of 4D BIM model. Since BIM model has the function of detecting collision items in design stage, the API developers can improve the function of creating virtual workspace among activities and shows the collisions in the BIM model, and therefore the criterion of workspace layout classification will be more usable for managers to solve the workspace conflict problem.

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