A SIMULATION MODEL FOR DECIDING AN OPTIMIZED 3D SHAPE OF CONSTRUCTION WORKSPACE CONSIDERING RESOURCES IN BIM ENVIRONMENT

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ABSTRACT: A construction workspace is considered as a critical factor to secure constructability and safety of a project. Specially, optimized size of each workspace helps to minimize any conflicts between workspaces, works and resources within a workspace in the construction site. However, since an existing method for making a decision workspace's size depends on generally experiences of managers and work conditions of activity, it is difficult to perform safe works considering feasible workspace size. The workspace size is changed according to the quantity of resources allocated into each activity as time progresses. Accordingly, it is desirable that optimized workspace size considering input size of resources is determined. To solve these issues, this study configures an optimized model for deciding standard size of workspaces by simple regression analysis and develops a visualized scenario model for simulating the optimized workspace shape in order to support BIM (Building Information Modeling) environment. For this, this study determines an optimized resource shape size considering maximum working radius of each resource and constructs its visual model. Subsequently, input size of resources for each activity is estimated considering safety execution area of resources and workspaces. Based on this, an optimized 3D workspace shape is generated as a VR simulation model of a BIM system based on the suggested methodologies. Moreover, operational feasibility of the developed system is evaluated through a case study for a bride project. Therefore, this study provides a visualized framework so that project managers can establish an efficient workspace planning in BIM environment. Besides, it is expected that constructability, productivity and safety of the project will be improved by minimizing conflicts between workspace and congestions between resources within a workspace in the construction phase.

Keywords: BIM (Building Information Modeling), Resource, Workspace conflict, Regression analysis, Workspace congestion, Optimized workspace size

1. INTRODUCTION

A workspace is a critical factor in order to perform a safe work [3]. Of note, the workspace shape created by resource allocation is requiring efficient and reasonable space planning as an available execution area of resources [2]. In existing researches [1] [10] in relation to workspace planning, configuration of space shape required for the workspace planning has been made focused on architectural elements. Besides, the size of workspace shape has been determined based on 2D drawings [10] and considering construction methods applied on site [1]. Therefore, it is difficult to create an optimized workspace shape, to analyze its utilization state according to resource input, and to check dynamically workspace conflict. Since the size of related workspace is fluctuated by resources to be inputted as time progresses, it is important to construct a series of methodologies for determining the optimized size of workspace shape that affect the productivity of projects.

The aim of this study is to configure methodologies for determining the size of an optimized workspace 3D shape and to develop a simulation scenario model for creating the workspace shape based on 4D CAD that enables the managers to operate in BIM environment as an alternative to improve the practical utilization of a workspace conflict verification system [4]. To do this, this study suggests a simple regression analysis model that enables to make a decision the size of a unique workspace for each activity by configuring a resource profile. With this, this study configures a changing model of workspace depending on distribution patterns of resources and a scenario model for a BIM-based 4D simulation [7] in order to create dynamically the workspaces to allow the suggested model to be extended into BIM environment.

Therefore, the suggested simulation model can establish an efficient input of resources and workspace planning to determine the size of an optimized workspace shape in the pre-construction phase. Besides, it can be utilized as a workspace analysis model that allows the

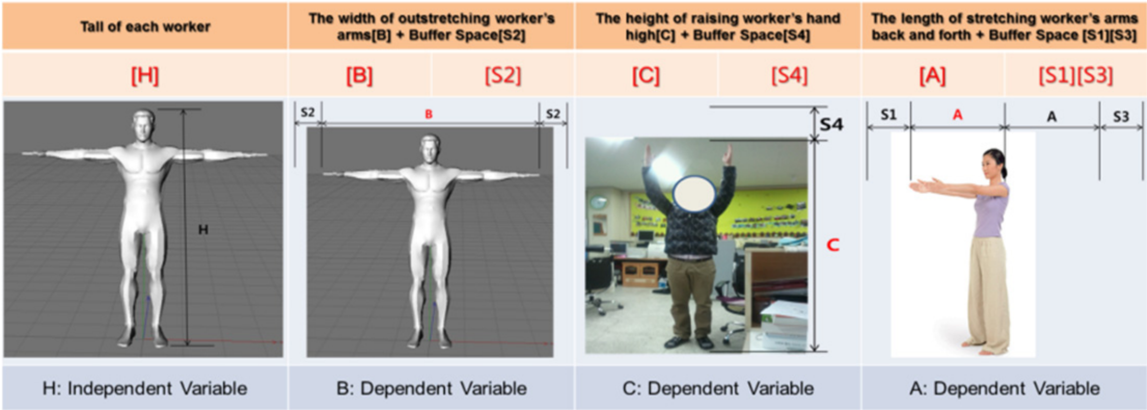

Fig. 1. Measurement Model of Workspace Shape for Each Worker

model to extend in BIM-based virtual environment. Specially, it is expected that the suggested model can be utilized as a framework to develop an optimized simulation model for workspace conflict check reflecting the changing model of workspaces by resource profile, which is required to rehearse the workspace conflict.

2. DEFINITION OF THE SIZE OF WORKSPACE FOR A WORKER AND ITS MEASUREMENT MODEL

As a safe work area, configuring the workspaces is essential in order to execute safe works and promote the productivity of activities. Thus, this study measured work types of workers and their body size targeting for 23 workers, which is allocated for critical activities, for 5 days to determine the standardized size of workspace for each worker. In order to determine the size of workspaces by activity type for each worker, as measurement parameters of workspace, the tall of a worker is ‘H’ like Fig. 1. In addition, the width of outstretching worker’s arms is ‘B’, and its buffer space is equally set to ‘S2’. The length of stretching worker’s arms back and forth is equally set to ‘A’, and its buffer space is defined as ‘S1’ and ‘S3’ respectively. The height of raising worker’s hand high is ‘C’, and its buffer space is specified as ‘S4’.

Using these parameters, the workspace shape determined by the measurement of standardized size for workers has generally a cube-shaped bounding box model. The workspace shape as an available maximum radius of inputted workers can be configured with the cubed-shape model, which has ‘WIDTH’, ‘LENGTH’, and ‘HEIGHT’ values with buffer space by reflecting the measured numerical value. Besides, a cylindrical workspace shape can be also built using the width of outstretching worker’s arms as the diameter of a cylinder and the height of raising worker’s hand high as the height value of the cylinder with their buffer space separately.

3. DECISION OF THE OPTIMIZED SIZE FOR WORKSPACE BY RESOURCE PROFILE

3.1 Estimation and Analysis of the Standardized Size of Workspace for Each Worker

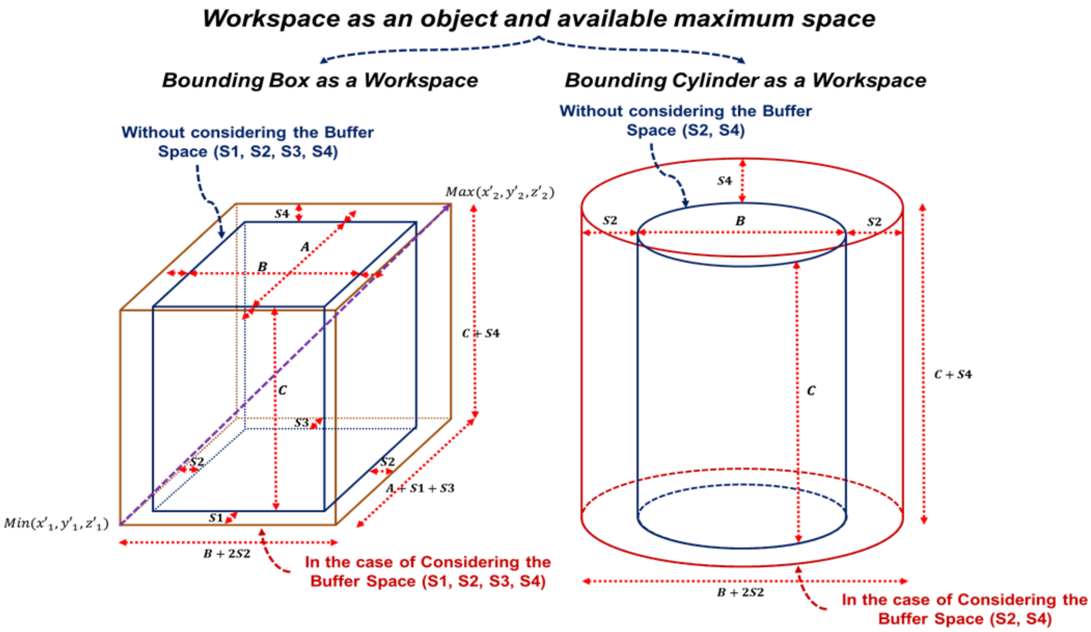

Fig. 2. Parameters for Creating 3D Workspace Shape with Buffer Space

As presented above, the size of workspace shapes, which is specified by the quantity of inputted resources, can be fluctuated. The feasible estimation of the size of workspaces is utilized to define the size of more accurate workspace shape as an object space. This study measured parameter values of workspace shape for workers with 'WIDTH (Width + Buffer Space)', 'LENGTH (Length + Buffer Space)', and 'HEIGHT (Height + Buffer Space)' considering work type and the height of each worker, and 'Length', 'Width', and 'Height' value' and those buffer space respectively with three parameters above. The former three parameters are factors that configure geometric shape of workspaces without considering the buffer space, while the latter three parameters are factors of geometric shape for workspace utilized by considering the buffer space.

To estimate the standardized size of a workspace shape for workers, this study analyzed work types by each activity for workers. With this, two types of workspace shape, which include cube-shaped bounding box and cylinder model, are considered as the standard shape of workspace for worker for considering the buffer space and vice versa in Fig. 2.

3.2 Decision Model of an Optimized Workspace Size by Simple Regression Analysis

The size of workspace by each worker type measured through site visit is determined by regression analysis that defines the size of workspace by each worker's height. The regression analysis is a method that calculates statistically functional relationship between the measured data in order to analyze correlation that exists between more than two variables. At first, a scatter plot should be drawn as a two-dimensional (2D) graph where the height of workers, which is the independent variable, is plotted along the 'X' axis and the size of workspace, which is the dependent variable, is plotted along the 'Y' axis. Here, in order to determine such dependent variables separately for 'Width', 'Length', and 'Height' according to the height of workers, a linear equation, which is y=1.278x-13.157, was drawn using a simple regression analysis that is provided from a function of Microsoft Excel in Fig. 3. Besides, we analyzed correlation with the 'Height (Y)' of workspace according the height of workers. In this process, coefficient of determination, which is 'R2' value, was derived as 0.8053. Thus, it is proved that the correlation is very high between two variables. Like this, the rest of 'Width' and 'Length' values according to the height of workers can also be estimated in the same way as proposed in this section.

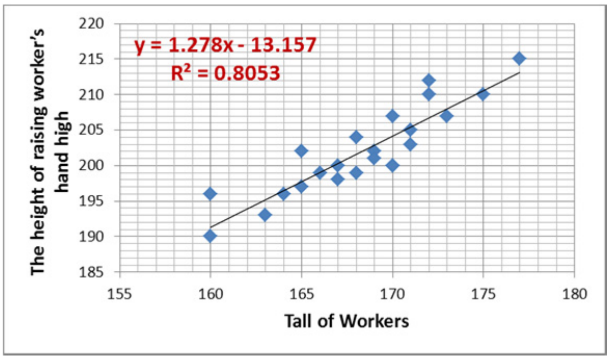

Fig. 3. Regression Analysis Model for Determining 'Height' of Workspace by Workers' Height

Finally, the size vales of 'Width', 'Length', and 'Height' of workspace according to the height of workers, which has drawn by each regression analysis function, are determined as marked in Fig. 4.

If the height of each worker is inputted as a value of the 'X' axis, the size of workspace 3D model, which includes 'Width', 'Length', and 'Height' for each worker, is estimated by a regression function. For example, if the height of a worker inputted to a construction element between 170cm and 175cm, the value of 175cm out of the two figures is defined as the independent variable in the 'X' axis. With this, using each regression function, the size of 'Width', 'Length', and 'Height' of cube-shaped workspace 3D model is specified as 171cm, 79cm, and 211cm separately. These values were defined without considering buffer space for each workspace of workers.

3.3 Analysis of the size of an optimized workspace for inputted resource

A required workspace of elements linked with an

Items	Tall of each worker	The width of outstretching worker's arms[B] + Buffer Space[S2]	The length of stretching worker's arms back and forth[A] + Buffer Space [S1][S3]	The height of raising worker's hand high[C] + Buffer Space[S4]
Regression Analysis	$x = H$	$y_1 = 0.7493x + 39.038$	$y_2 = 0.5424x - 16.18$	$y_3 = 1.278x - 13.157$
Correlation Coefficient	-	$R^2 = 0.5613$	$R^2 = 0.5507$	$R^2 = 0.8053$
Example	$x = 165cm$	$y_1 = 162.6725 \fallingdotseq 163cm$	$y_2 = 73.316 \fallingdotseq 74cm$	$y_3 = 197.713 \fallingdotseq 198cm$
	$x = 170cm$	$y_1 = 166.419 \fallingdotseq 167cm$	$y_2 = 76.028 \fallingdotseq 77cm$	$y_3 = 204.103 \fallingdotseq 205cm$
	$x = 175cm$	$y_1 = 170.1655 \fallingdotseq 171cm$	$y_2 = 78.74 \fallingdotseq 79cm$	$y_3 = 210.493 \fallingdotseq 211cm$
	$x = 180cm$	$y_1 = 173.912 \fallingdotseq 174cm$	$y_2 = 81.452 \fallingdotseq 82cm$	$y_3 = 216.883 \fallingdotseq 217cm$
Space Type	Bounding Box	O	O	O
		$The\ size(Volume)\ of\ Bounding\ Box = Width(y_1) \times Length(y_2) \times Height(y_3)$		
	Cylinder	O	X	O
		$The\ size(Volume) of\ Cylinder = \pi \times (^{Width(y_1)}/_2)^2 \times Height(y_3)$		
	x: Independent Variable	y_1: Dependent Variable	y_2: Dependent Variable	y_3: Dependent Variable

Fig. 4. Decision on the Size of 3D Workspace Shape by Simple Regression Function

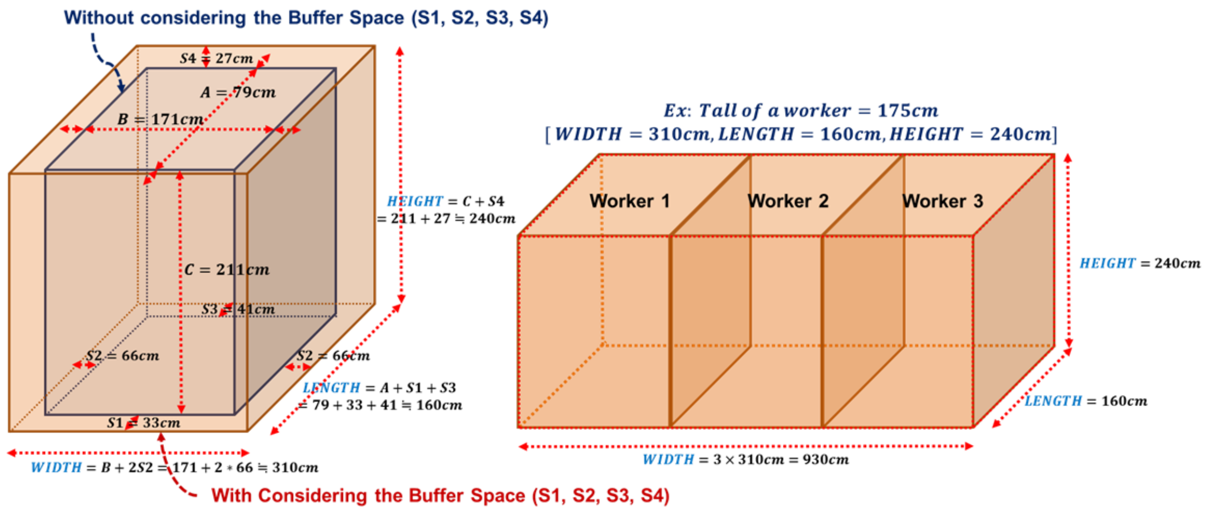

Fig. 5. 3D Workspace Shape for Multiple Workers Determined by Both Regression Equation and Buffer Space

activity can be determined by the size of 3D objects of construction elements and the quantity of inputted workers. As analyzed in a previous section, the workspace shape required in days by elements is determined based on resource profile inputted into a system.

Suppose that there is an activity that has the duration of 5 days. Before creating workspace, the quantity of allocated resource and its distribution graph allocated to 'Activity 1' need to be confirmed by the managers. For instance, in an initial generation stage of workspace, a bounding box model that envelops completely an element object is created as an object space using both minimum and maximum coordinates of elements. Besides, the size of the workspace shape for the quantity of inputted workers is determined based on daily changing profile of workers. To create workspace 3D models for multiple workers, the size of a workspace for one worker, which is 175cm tall, is set 3.1m, 1.6m, and 2.4m separately as the value of 'WIDTH', 'LENGTH', and 'HEIGHT' using parameters drawn by a simple regression analysis and buffer space. If three workers, which have the same tall, are allocated, all workers have a workspace model, which has the same 'WIDTH', 'LENGTH', and 'HEIGHT' (Fig. 5).

Like this, if the size of workspace for each worker is decided, the size values of the workspace for the workers need to be reflected to the corresponding space area in order to configure an object space created in an initial stage as an entire workspace.

3.4 Configuration of a changing model for workspace shape by resource profile

In this section, a workspace by resource profile is created assuming cube-shaped type. As analyzed in a previous chapter, the suggested model for workspace generation is considering a condition that the same size of workers is inputted. However, according to the execution characteristics of works, the input quantity of workers can be different. Therefore, the input quantity of workers should be properly managed by a resource change profile. The profile is divided into three types, which include uniform distribution, triangular increase, and three steps.

The first pattern is a uniform distribution without varying resource input from start to end date of an activity. There is no change in the size of workspace shape until activities finish from the start date. The second pattern is a distribution type that the input quantity of workers increase linearly from start to end date of an activity. Accordingly, the size of workspace by the distribution pattern increases also linearly. The third pattern is a distribution type that the input quantity of workers increases linearly from start to a certain time of an activity, then for a certain period of time, the pattern type follows a uniform distribution. For the rest of the time, the distribution is linearly decreased from a certain point to end date of an activity. Accordingly, the size of workspace shape increases linearly, then the size is kept uniformly for a certain period of time. Finally, it shows that the size by resource profile is decreased linearly.

4. A SIMULATION MODEL FOR CREATING AN OPTIMIZED WORKSPACE BASED ON BIM

This chapter configures a scenario model for a workspace generation simulation based on 4D CAD with the suggested method for creating workspaces by a resource profile. The simulation model for workspace generation was constructed considering the case that the suggested method was applied by using a workspace conflict verification system [8] developed by our research team in a previous project. A visual simulation model requires an input profile of resources allocated into each activity, 4D model [6] [7] [9], which is linked schedule by WBS [5] with 3D element model, and workspace planning data for works. Fig. 6 represents a workspace generation model and a scenario of its changing simulation configured by a resource profile.

A resource profile for each activity should be first inputted into the system. The resource profile should have the input quantity of workers allocated to each activity in days. Based on the assigned result of resources, a fluctuation distribution graph of resources is determined.

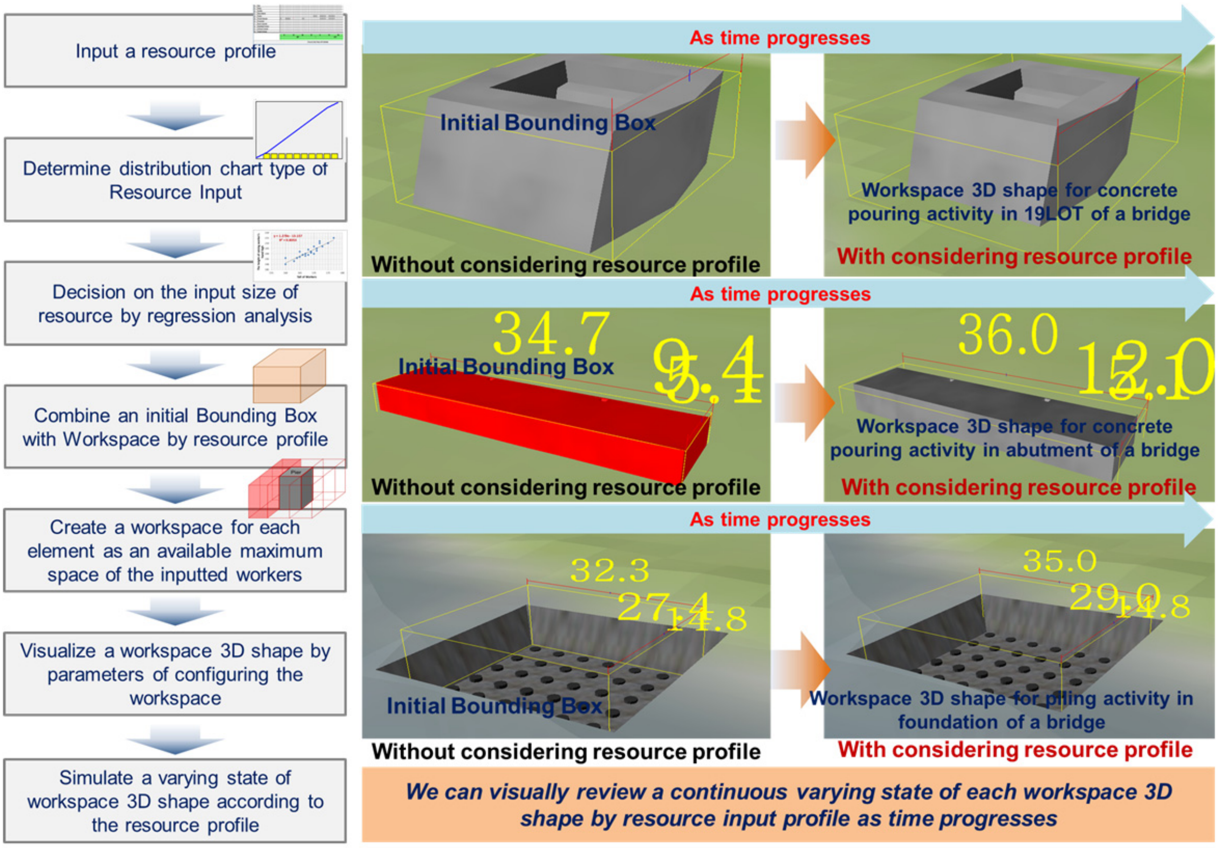

Fig. 6. A Scenario Model for Workspace Generation and Change Simulation by Resource Profile based on BIM

After completing analysis of a resource profile, a workspace shape is created according to distribution patterns of workers for each activity. A bounding box model is first created as an object space that envelops element models. Subsequently, the size of workspace shape is determined according to the quantity of inputted workers in days by a resource profile. The workspace shape is automatically configured by a linear regression function that determines 'WIDTH', 'LENGTH', and 'HEIGHT' values of a workspace 3D model with buffer space for each worker. Accordingly, the size of the optimal daily workspace for each activity is determined by a resource profile. Through these processes, the daily workspace shape for each activity is configured by parameters, which include 'WIDTH', 'LENGTH', and 'HEIGHT'. Such parameters are referred as visual properties for workspace 3D model, and then by embedding the parameters into an algorithm, a cube-shaped workspace 3D model is automatically created. Then, if layout location of the workspace is changed, new layout location should be defined using the same processes configured in the existing system. With these methods, an optimized 3D workspace model can be visually reviewed. The final workspace model for each activity is going to be utilized by considering the workspace shape for each worker determined by a resource profile with an enveloped bounding box of each element.

5. CONCLUSIONS

The study determined the size of an optimized workspace shape targeting for many workers in construction sites and developed a BIM-based 4D simulation model as a scenario in order to configure dynamically a generation system of workspaces by schedule and resource input pattern. The body measurement model for site workers is constructed to extract geometrical parameters as a decision factor of the workspace size. With this, numerical values of certain worker body for determining the workspace 3D shape for workers are measured personally through site visit. Subsequently, a scatter plot that enables to form the values of 'Width', 'Length', and 'Height' of a workspace shape by the height of workers was constructed separately. Then, a simple regression function that determines each parameter by the height of a worker was drawn. After constructing a simple regression equation, a changing model of workspace shape was configured considering the quantity of resource inputted during the execution period of each activity and fluctuation pattern of the resource by a resource profile. Based on this, a scenario model for 4D simulation that enables to dynamically operate within BIM environment was made in order to confirm visual change state of workspace shape that varies according the input size of resources as time progresses.

Thus, the suggested model can be utilized as a critical factor that measures productivity of given activities by evaluating resource congestion within a workspace that each activity has. In addition, this can be applied as a base model that enables the managers to analyze dynamically conflicts amongst workspaces by determining the size of an optimal workspace shape. Specially, it can be utilized as a framework that can extend to BIM environment. Moreover, it is expected that the suggested model will be operated as the BIM-based simulation model for creating 3D workspace models across the entire construction industry, which includes architecture and plant industry as well as civil engineering projects.

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