A Critical Review of Recent Progress on Construction Workspace Planning Using BIM

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Abstract
Effective workspace planning and management are critical in managing construction productivity, cost, and safety. Due to the dynamic nature of workspace planning it is difficult to evaluate different workspace utilization alternatives when using traditional 2D layout tools. Emerging 4D BIM modeling tools enable the capture of the projects' dynamic characteristics of workspace utilization, and thus allow researchers to develop 4D simulations to better assess different workspaces options. In this paper the authors reported recent progress on construction workspace planning using 4D BIM models.
Based on recent research papers, the review was grouped according to three main stages in workspace planning: (1) workspace generation; (2) workspace problem identification; (3) workspace problem resolution. Then the authors strived to identify the most efficient elements in in workspace planning using BIM which fall into 4 main categories: (1) efforts and time; (2) visualization and communication; (3) predefined and validated processes; (4) global understanding. The paper concludes by proposing an efficiency criteria to further evaluate the technical progress and solutions reported in the paper.

Keywords: Workspace, BIM, construction

1 Introduction

Inappropriate workspace planning can lead to loss of productivity, safety hazards, and poor quality (Choi et al. 2014; Kaming et al. 1998; Oglesby et al. 1989; Zhang et al. 2007). As a result, a project manager should consider the workspace as one of the critical tasks to be managed at a construction site, alongside time, cost, laborer equipment and material (Akinci et al. 2002a; Chavada et al. 2012; Choi et al. 2014; Dawood and Mallasi 2006; Tommelein and Zouein 1993). A project manager should be able to prevent workspace problems and their negative effects on project performance (Choi et al. 2014). Various researchers have developed integrated approaches, embracing the dynamic and complex features of workspaces. With the purpose of having a general understanding of the problem, different papers have been considerate. The aim of this review is to summarize the best achievements and define which elements most affect efficiency in workspace planning.

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2 Literature review

This review has taken into account several papers that approach different aspects of workspace planning. However, the review will focus on the papers that has been considered the most comprehensive and complete:

- Thabet and Beliveau (1994), Modeling work space to schedule repetitive floors in multistory buildings
- Guo (2002), Identification and Resolution of Work Space Conflicts in Building Construction
- Akinci et al. (2002b), Representing Work Spaces Generically in Construction Method Models

- Akinci et al. (2002c), Formalization and Automation of Time-Space Conflict Analysis
- Dawood and Mallasi (2006), Construction Workspace Planning: Assignment and Analysis Utilizing 4D Visualization Technologies
- Chavada et al. (2012), Construction Workspace Management: the Development and Application of a Novel nD Planning Approach and Tool
- Choi et al. (2014), Framework for Work-Space Planning Using Four-Dimensional BIM in Construction Projects.

This review analyzes workspace planning processes proposed by various researchers. Primary references has been the studies of Chavada et al. (2012) and Choi et al. (2014), whose workspace planning processes has been individuated as the most completed.

In the study of Chavada et al. (2012) the management of workspaces is enabled in a 5D planning environment (3D, time and cost) through 4 main steps: workspace generation and allocation process, conflict detection process, congestion detection process and resolution process.

Choi et al. (2014) proposed a specific process for workspace problem resolution to be managed through a 4D Building Information Model (BIM) environment and is made by 5 steps: 4D BIM generation, workspace requirement identification, workspace occupation representation, workspace problem identification.

For the purpose of this review previous steps will be grouped as follow:

1. Workspace generation:
    - Workspace generation and allocation (Chavada et al., 2012)
    - 4D BIM generation, workspace requirement identification and workspace occupation (Choi et al., 2014)
2. Workspace Problem Identification:
    - Conflict detection and congestion detection (Chavada et al., 2012)
    - Workspace problem identification (Choi et al., 2014)
3. Workspace Problem Resolution:
    - Resolution (Chavada et al., 2012)
    - Workspace problem resolution (Choi et al., 2014)

All other researchers' processes will be identified according to these 3 main steps. Often previous researchers' processes have been found to be uncompleted. However it is important to review those in order to achieve a much comprehensive knowledge of most recent studies and understand their background.

2.1 Workspace generation

In the research of Thabet and Beliveau (1994) two parameters characterized work space constraints for any activity: work space demand parameter, which defines the space necessary to accommodate any activity in a specific work area and the work space availability parameter, which is the amount of space available for any activity during the time period the activity is considered for scheduling. In their methodology they first identified the physical spaces available within an AutoCAD environment. Then these spaces were broken down into work blocks and activities were allocated to the work blocks. A work block defined a particular location in the work area during a particular time period of construction. So, the suggested scheduling method was integrating space demand and availability by comparing required space and available space for each activity in a specific work block.

Researchers founded important limitations in this approach in the effort required in manually extracting and inserting data from within the CAD environment. So, the need for the creation of 4D databases was identified.

Guo (2002) adopted parameters defined by Thabet and Beliveau (1994) of space availability and space demand. He divided the available space into four categories: exterior of the jobsite, interior of the jobsite, inside the structure, and space provided by temporary structures such as platforms and scaffolds. The space demand was derived from the original schedule and broken down as a hierarchical structure: every activity was divided in tasks; every task required labor, equipment, material and temporary facilities; labor and equipments needed working space and path space, materials needed storage space and waste space and temporary facilities needed set up space.

Different types of space demand were identified within CAD with different patterns and different colors were assigned to each activity in order to detect easily the space user. This presented reduced automation in terms of execution and cannot handle the dynamicity associated with construction activities and their required workspaces.

Akinci et al. (2002b) tackled the need for a generic project-independent representation of workspaces, from which the project-specific instances of spaces can be derived automatically based on project-specific design and construction schedule information. First they proposed a new classification of workspaces. Riley and Sanvido (1995) first had identified 13 types of spaces required by construction activities. These were building components, layout areas, unloading areas, material paths, personnel paths, storage areas, staging areas, prefabrication areas, crew areas, tool and equipment areas, debris paths, protected areas, and hazard areas. Also Guo (2002) had defined 4 types of workspaces: working space (for laborers and equipment); storage space and waste space (for materials); set-up space (temporary facility space). Akinci et al. (2002b) classified the 13 spaces defined by Riley and Sanvido (1995) into 3 categories:

1. Macrolevel spaces: the large-scale spaces located across sites;
2. Microlevel spaces: the spaces required within the proximity of the components being installed;
3. Paths: the spaces required to be left clear for transporting people, material, and debris.

The researchers focused on micro-level spaces, which constitute core activity space requirements associated with direct installation work. Therefore, any problem resulting from spatial conflicts between the micro-level spaces required by two different activities directly impacts the workflow at construction sites (Howell and Ballard 1995; O'Brien et al. 1997; Riley and Sanvido 1997; Akinci et al. 1998; Akinci and Fischer 2000b).

Until the study of Akinci (2002b), many previous studies focused on representing macro-level spaces required by construction activities (Tommelein et al. 1992; Tommelein and Zouein 1993; Choi and Flemming 1996; Choo and Tommelein 1999; Hegazy and Elbeltagi 1999; Zouein and Tommelein 1999). A few investigated how to model micro-level spaces (Rad 1980; Riley 1994; Thabet and Beliveau 1994; Riley 1998). All of the researchers who modeled micro-level spaces discussed the dynamic nature of activity space requirements and identified the spatial-temporal attributes necessary to represent the project-specific workspaces (Rad 1980; Riley 1994; Thabet and Beliveau 1994; Zouein an Tommelein 1994; Riley 1998). In particular, Mawdesley et al. (1997) stated that the Gantt chart technique, mostly used by project managers, does not furnish a communication medium on how the project activities on the construction site are to be executed. In fact it doesn't catch the visual interaction between the construction activities being not entirely adequate for rehearsing construction activities, both in space and time.

Akinci et al. (2002b) understood that one of the most important limitations of the majority of previous studies was that users were asked to manually enter the project-specific instances of spaces required by construction activities. Consequently they didn't adequately provide a representation that makes it practical for construction professionals to define the spaces that they need generically in relation to the construction method that they are going to use. With their research they first tried to give a solution to the need for an automated approach for the generation of project-specific activity space requirements. They formalized generic descriptions of spaces in a computer-interpretable way such that subcontractors could describe the spaces they need generically, and such that a computer system automatically interpreted that knowledge according to project-specific design and schedule information to generate the project-specific workspaces represented in four dimensions. They implemented a prototype system, 4D Planner Space Generator (4D SpaceGen), which incorporates this ontology to automatically generate spaces.

Dawood and Mallasi (2006) focused on the dynamic nature of the construction activities' workspaces. They understood that there was a need for a proper representation of the dynamic nature of the construction activities' workspaces in 3D space and time and proposed a dynamic visual planning: they believed that project managers should be able to visualize construction plans and simulate different scenarios of schedules. Moreover they focused on the identification of activity execution workspace, which referred to the facilities of identifying 3D execution space for any given activity in any given week: for every product that needed to be constructed in a given week, a 3D work space have been assigned.

Moon et al. (2009) proposed an integrated approach where workspaces are assigned individually to a model's object and linked to schedule activities. They classified and allocated workspaces using a semiautomatic generation method based on resource requirements. Limitations were founded since workspace was assigned using a bounding volume and performed individually for each model object. Planners in practice tend to identify the required workspaces not only based on model objects but also on schedule activities. Finally their approach was based on AutoCAD rather than BIM and lacked strategies for conflict resolution.

Bargstadt and Elmahdi (2010) developed a method for identifying workspaces requirements called "The Spatial Network" where workspaces were considered only at a high level of detail as the Work Step Process (WSP). They broke down tasks into subtasks and subtasks into objects. Each object was composed of different elements or sections. So they created a simulation tool to assist project managers to plan and coordinate different trades within highly congested work areas but they didn't include in their research a 4D visualization capability or strategies for conflict detection and resolution.

Chavada et al. (2012) focused on the necessity of generation, allocation and management of workspaces in a 4D/5D BIM environment. In previous studies categories in which there were the majority of limitations were the allocation of workspaces and the IT environment in which workspace management was performed. Workspaces were generated in 2D drawings or 3D design within the design authority tools (e.g. AutoCAD or BIM), not including the time-dimension and making difficult to identify the requirements in terms of workspaces at a particular project date (Guo, 2002; Dawood and Mallasi, 2006; Bargstadt and Elmahdi, 2010; Kuan-Chen and Shing-Chung, 2009; Wu and Chiu, 2010). Few researchers (Akinci et al., 2002b; Moon et al., 2009) allocated construction workspaces in 4D environments, were the fourth dimension was the time. Moreover workspaces were mostly assigned individually to objects instead of activities, in isolation of planning environment and unable to consider workspaces such as storage workspace, which is not associated with a specific object. These processes were impractical for models with high numbers of objects and may not be required in real life scenarios as multiple objects could be sharing the same workspace. Beside workspace management resulted separated from the scheduling.

In order to allocate and generate workspaces Chavada et al. (2012) first proposed a new classification of workspaces. Beside aforementioned classification of workspaces suggested by Riley and Sanvido (1997), Guo (2002) and Akinci et al. (2002b), further classifications were developed.

Chavada et al. (2012) developed a classification of workspace types by adopting a similar terminology to the one used in the manufacturing sector, which distinguishes between value added and non-value added activities:

- Main workspaces: workspaces associated with activities, which contribute to physical changes to the building or are in direct contact with the building. Those are value added activities.
- Support workspaces: workspaces required for activities, which do not contribute to the physical progress of the construction. Those are non-value added activities
- Object workspaces: areas or volumes of elements included in the model drawings. They are the only category of workspace that is considered permanent.
- Safety workspaces: areas that allow a tolerance between two workspaces to prevent safety hazards.

In their methodology workspaces were generated in a 5D environment and assigned to either the activities or objects in an interactive way. They first proceeded with allocation of resources and identification of the required support infrastructure for each activity. That information was used to assign the workspaces through a 3D mark-up within the 5D planning environment: the user inputted the approximate workspace size and type and generated a bounding box, which represented the workspace by considering the construction method. Then they positioned the workspace generated and linked it to one or more activities in the schedule.

One of the most important improvement given by this study was that the workspaces could be generated within a 5D environment in an interactive manner and could be allocated to activities or objects using "1 to n" and "n to 1" relationships, while in previous studies workspaces were generated within the CAD environment and allocated to objects. However the assumption that all workspaces could be represented with prismatic rectangular shapes that were aligned along the three major axes is one of the limitations of the proposed approach, which demonstrated the need for alternative bounding techniques and intersection tests to be identified.

Choi et al. (2014) classified workspace by its function and movability. In fact they believed that before suggesting a framework for the workspace planning process, characteristics of a workspace should be comprehended. In previous studies they found that often all types of workspaces were generated by identical method regardless of the characteristics of each workspace type, being not able to reflect the different nature of workspace types. Their classification by function was based on Riley and Sanvido's (1997) classification: and defined six functional workspace types: object space, working space, storage space (direct workspace); setup space, path space, unavailable space (indirect space). Their classification by movability defined fixed workspace and flexible workspace. There were some correlations between the two classifications: object space and working space were fixed workspace; storage space, set up space and path space could be fixed or flexible workspace; unavailable space was a fixed space.

Choi et al. (2014) stressed the necessity of construction method and material information databases for workspace requirement identification. The construction method database contains information about construction method selection criteria for each activity type and the spatial relationship between the object and working space that each construction method requires. The material information database includes information about the physical features of each material, as well as the quantitative relationship between activities and materials.

In the study of Choi et al. (2014) it is interesting how they distinguished between workspace requirements identification and workspace occupation identification. Workspace requirement is defined as an entire space that is required for all resources of on activity during the entire duration of the activity. It differs from workspace occupation, which is a partial space of the workspace requirement that is used by workers, materials or equipment during a unit time period. To execute an activity, workspace occupation successively passes through the workspace requirement during the activity duration. In previous studies there was the assumption that resources for activity execution occupied their required workspace for the entire duration of the activity (Akinci et al. 2002b; Chavada et al. 2012; Guo 2002; Winch and North 2006). This resulted in failing to achieve an accurate representation of workspace utilization status. In fact, in a real construction process, the activity is executed by successive and repetitive occupation as part of the workspace requirements (Riley and Sanvido 1995). Therefore, the pertinent methods for the representation of workspace occupation status are necessary to predict the actual workspace problems.

This review has identified the study of Choi et al. (2014) as one of the best effortsin the workspace generation: the differentiation made by the researchers between workspace requirement and workspace occupation is one of the most relevant findings of the study. In the paper reviewed, most common limitations have been founded as too much effort is required in this first phase to input data.

2.2 Workspace problem identification

Thabet and Beliveau (1994) didn't develop a space conflict analysis but introduced the idea of space congestion stressing the problem of productivity loss due to space constraints. To quantify the decrease in productivity rate because of limited work space, a space capacity factor (SCF) was proposed to measure the degree of congestion in any given work block of the floor. They stated: SCF = SDA / CSA. Where SDA (Space Demand for Activity) defined space needed for manpower and equipment and handling of material within the floor area and CSA (Critical Space Availability) was the amount of space available for any activity during the time period the activity is considered for scheduling. The space capacity factor can be plotted against different productivity rates for construction activities: productivity-SCF curve were produced. A limitation of these approach was that actual curves showing the relationship between the SCF and the productivity rate for different construction crews needed to be developed for different activities or group of activities to reflect the actual variation of crew productivity under various limited space conditions.

According to Guo (2002) space conflict was defined as more than one space demand claim on a specific available space during the same time period. Thus, when all of the space demands of various subcontractors are overlapped on the CAD drawing for a specific time period, space conflicts can be detected. In his research Guo (2002) stressed the importance of measure certain data regarding the affected activities once a space conflict is detected in order to proceed with analysis and resolution. Data required were: interference space size (size of overlap between activities), Interference Space Percentage (ISP=interference space size/original size), interference duration, Interference Duration Percentage (IDP=interference duration/original duration). With this approach he was one of the first introducing the necessity of classification of workspace conflicts through the ISP and IDP.

Earlier, Riley and Sanvido (1997) proposed a manual space planning method that provided a logical order and priority for space planning decisions. No quantification of space conflict was attempted but the model provided a particular new way in which planners should consider and plan spaces. Later, for the same purpose of give an answer to the need of classification of workspace conflicts, Akinci et al. (2002c) developed a space-time conflict taxonomy and identified conflict ratio and clash severity.

Akinci et al. (2002c) first picked out three characteristics that make difficult for project managers to identify, analyze, and manage spatial conflicts without the help of a computer system:

1. Temporal aspects of time-space conflicts, meaning that time-space conflicts between activities only occur for certain periods of time;
2. Multiple types of time-space conflicts, depending on the types of spaces conflicting and the ratio of the volumes of the conflicts to the volumes of the required spaces;
3. Multiple conflicts existing between a pair of conflicting activities.

As suggested by the previous study (Akinci et al., 2002b), they addressed these challenges associated with the time-space conflict by automating:

- The detection of spatial conflicts in all x, y, z and time dimensions,
- The categorization of the conflicts detected according to a taxonomy of time-space conflicts
- The prioritization of the conflicts categorized in cases where multiple types of conflicts exist between the same activities.

To automate the time-space conflict analysis process Akinci et al. (2002c) developed a prototype system, 4D WorkPlanner Time-Space ConflictvAnalyzer (4D TSConAn).

The study deeply developed the issue of time-space conflicts analysis but presented some limitations:

- The detection of time-space conflicts is limited to rectangular prisms located parallel to orthogonal planes, representing and reasoning about complex geometric shapes was suggested;
- Time-space conflict taxonomy includes only micro-level activity space requirements but reasoning about macro-level spaces and paths should have been included;
- Prioritization of time-space conflicts only ranks conflicts between pairs of conflicting activities when it should have been applied throughout the whole project.

Dawood and Mallasi (2006) introduced and discussed a Critical Space Analysis (CSA) methodology and a 4D simulator dubbed PECASO (Patterns Execution and Critical Analysis of Site-space Organization) to identify workspace conflicts in a construction site. Their methodology utilized a structured query language (SQL) to organize the product's coordinates to the required execution sequence, and a layer in AutoCAD to assign workspaces. The workspaces were then linked to activities in order to provide a 4D simulation of workspaces. While this approach was theoretically capable of dealing with the dynamicity of construction workspaces, it was difficult to implement it in practice, as the project planner was required to assign construction workspaces with CAD. The other limitations of this work were the lack of interactivity and its inability to incorporate real-time decisions by planners and project managers.

Wu and Chiu (2010) proposed a 4D workspace conflict detection and analysis system. They utilized Bentley Microstation for 4D visualization and developed a plug-in extension to identify design, damage, safety and congestion conflicts on site. Limitations were founded since the work relied on third party system and did not consider any resolution strategy to resolve the identified conflicts.

Chavada et al. (2012) observed that previous studies had often utilized AutoCAD to assign and to detect the conflicts in workspaces even if project planners were often unfamiliar with those tools. As mentioned before, they enabled the management of workspaces by integrating the current planning process and BIM data of construction models within a 5D planning environment, where workspaces were first generated and assigned by planners in an interactive way and then conflicts and congestion were detected and resolved within a 5D planning environment. In addition, in this phase, they focused both on detection of conflicts and analysis of workspace congestion.

Detection of conflicts included both detection of temporal conflicts ("schedule conflicts") between schedule activities and spatial conflicts ("workspace conflicts") between workspaces. Detection of schedule conflicts was required as a preliminary condition to be checked prior to the workspace conflicts. This was one of the most interesting findings of the research, which, in addition with the practice of the "intersection test" between bounding boxes, improved the accuracy for the detection of workspace conflicts. Moreover they introduced the necessity of calculating the Severity of the Conflict (SC) once the process detects a conflict in order to filter activities as critical and non-critical activities and establish a prioritization for the resolution.

Chavada et al. (2012) believed that in close conjunction with the identification and resolution of conflicts, workspace congestion was as a major cause of productivity loss on construction. Workspace congestion was defined by Chavada et al. (2012) as a situation that occurs when the workspace available for the resources of an activity or group of activities is either limited or smaller than the required workspace for such resources. Thus, even if there are no conflicts, a congestion test is still required as congestion may occur in cases where there are no spatial and/or temporal conflicts. Several researchers had tackled the issue by proposing a variety of optimization techniques with different sets of variables (Sriprasert and Dawood, 2003; Soltani and Fernando, 2004; Jang et al., 2007; Mallasi, 2009). Previous studies suggested different formulas and definition to calculate and consider workspace congestion, where the workspace criticality was determined by the supply and demand of resources on site: Space Capacity Factor (SCF) by Thabet and Beliveau (1994); "spatial loading" (s) by Winch and North (2006); the function for the ratio of conflicting workspace volumes (f(co)) by Dawood and Mallasi (2006); Space utilization (Us) by Chua et al. (2010). Chavada et al. (2012) measured the workspace congestion through the Congestion Severity (CgS), which express the congestion level for each activity as the ratio between the available workspace and the required workspace for the resources allocated to the activity. To calculate the severity of congestion, data about the unit volume of each resource used on site were required. In previous research, data about the space required by each resource unit appeared to be varying in a wide range. Chua et al. (2010) assumed that each laborer requires a space of 0.6 m3. Horner and Talhouni (1995) stated that 28.3 m2 as the desirable lower limit for effective task execution. Thomas and Smith (1990) suggested that 19 m2 per person was required. In the research of Chavada et al. (2012) a decision was made to leave these data as user inputs so the different needs of different users could be accommodated. Once the CgS was calculated for each workspace, the system utilized three thresholds and color coding (green, blue, and red) in order to visually communicate congestion in real-time 4D simulations. Moreover three congestion levels were defined: low (1-33%), medium (34-66%) and high (more than 66% and can exceed 100%), which could be visualized using green, blue and red, respectively.

Choi et al. (2014) defined the workspace problem as a situation where the workspace for conducting an activity is not available. This situation can occur when different activities are required to occupy a specific space during the same time period or when resources for activity execution cannot be accessed at their workspace because of obstruction created by other workspaces. Therefore, they stated that the workspace problem identification should include detecting not only workspace conflicts but also blocked paths. Choi et al. (2014) adopted the wall follower algorithm proposed by Madhavan et al. (2009) to develop their path analysis, which was defined as a process investigating whether or not available path space for all the resources at a construction site exists. Choi et al. (2014) defined a process to detect workspace conflicts in a 3D environment developing the concept of 3D bounding volume. In fact the algorithm that generates minimized bounding volumes of the objects and identifies the interface between each bounding volume detected virtual spatial collisions in a 3D model. 3D bounding volume were categorized by its shape by:

- Bounding Spheres (BS): identifies a spatial collision by comparing the sum of two bounding spheres' radii and the distance between the centers of two spheres (Talmaki and Kamat, 2012);

- Axis-Aligned Bounding Boxes (AABB): detects spatial collision by comparing the minimum and maximum coordinate values of the two bounding boxes that are parallel to their coordinate axes (Choi et al., 2014);
- Oriented Bounding Boxes (OBB): generates minimized bounding boxes by identifying the existence of a separating axis (DeLoura et al. 2000; Moller and Haines 2002).

Chavada et al. (2012) made significant contribution to the workspace problem generation by focusing on both detection of conflicts and analysis of workspace congestion. Moreover the process for the detection of conflicts enabled both temporal and spatial conflicts where the first were preliminary to the seconds. This results in a complete understanding of the workspace problem identification. In the papers reviewed, most common limitations have been founded in lacks on problems prioritization analysis.

2.3 Workspace problem resolution

Thabet and Beliveau (1994) identified factors to be considered in order to make scheduling decisions when space demand exceeds space availability: activity space demand, activity continuous status, maximum number of activity splits, activity space demand class, space capacity factor, minimum productivity rate. Then, they considered three possible actions: decrease production rate, interrupt flow of activity and delay activity start. Even if they didn't propose a real resolution process, they considered the possibility of allowing space overlap. In that sense they suggested that the decrease of crew productivity in work areas with limited space availability could have been utilized as a scheduling decision option during scheduling of such activities. Instead of delaying an activity, the activity was scheduled with a lower production rate than the normal value.

Guo (2002) considered three resolution strategies to overcome space conflicts:

1. Adjust the space demand, which changes the location of the space demand, or divide the original space demand into several smaller areas;
2. Adjust the planned schedule;
3. A hybrid approach, which adjust the space demand and scheduling sequence simultaneously.

Then he underlined the importance of prioritization of the activity to be modified and, like Thabet and Beliveau (1994), he considered overlapping workspaces. He identified seven criteria (logical sequence between activities, critical path, space divisibility, location change, space size modification, start time of conflicting space occupation, length of occupancy time) and affiliate criteria that also help resolve conflicts such as size of the conflict, location of the conflict, duration of the conflict, interference space percentage (ISP) and interference duration percentage (IDP).

Chavada et al. (2012) implemented the conflict resolution process, which, although fundamental to the management of workspaces, was absent in the majority of previous studies. At that moment, only two studies (Bansal, 2011; Guo, 2002) had included conflict resolution processes in their methodologies, which utilized the conflicting activities and the sizes of overlapping workspaces. Chavada et al. (2012) proposed a heuristic resolution process. Heuristic is a way of solving the conflicts by using resolution strategies that are based on a set of rules, which derive from user's experience, historical data and site observation. These strategies included: changing the start date of a conflicting activity; changing the duration of a conflicting activity; changing the size of the workspace, and changing the physical location of the workspace. The process proposed, being heuristic, was limited since relied on personal skills and experiences of the users involved.

Choi et al. (2014) asserted that, in the workspace problem resolution phase, Project Manager should consider the movability of the workspace, criticality of any activity, activity execution plan and material management plan. Their study was presenting a formalized procedure for workspace problem resolution, which often lacked in previous studies. The procedure proposed by Choi et al. (2014) consisted of six workspace problem resolution strategies. The procedure required that the strategies should have been applied in accordance with the following sequence:

1. Change the location of flexible workspace
2. Change the schedule plan for noncritical activity
3. Change the activity construction plan
4. Change the schedule plan for critical activity
5. Change the activity logic

6. Validation of selected resolution strategy

This review has identified the study of Choi et al. (2014) as the best achievement earned for the workspace problem resolution, as they were the ones that proposed the most validated formalized procedure. In the papers reviewed, most common limitations have been founded as too often resolution of problems relied only on the abilities and experience of the project manager.

3 Efficiency in workspace planning

In this review a summary of the best achievements in the field of workspace planning has been provided. After an investigation of the most comprehensive and complete papers has been proceed, this review will try to identify which are the elements of the workspace planning that most affect efficiency of the process.

Efficiency can be defined as the ratio of the useful work performed in a process and the total energy expended (The American Heritage Science Dictionary, 2014). In the case of workspace planning, the useful work performed in a process can be identified as the workspace problem identification and workspace problem resolution. The total energy expended is mostly characterized by the efforts spent for input data in the phase of workspace generation. Most of the workspace planning processes proposed result to be effective, but limitations have been founded in their efficiency.

This review has found that elements that make the process more efficient can be grouped in 4 main categories:

- *Efforts and Time*. Limitations in time and efforts required in input data for the workspace generation have been found in the majority of papers reviewed. The process will work if it requires a lower level of time and energies in the first phase to input and extract data. This will increase process efficiency.
- *Visualization and Communication*. Limitations have been founded in the way parties involved in the project are enabled to visualizing, communicating and handling data in order to immediately apply those in the management and with a low level of extra effort. Data should be easily visualized and communicated among different parties with accessible and understandable tools.
- *Predefined and validated processes*. Few papers have proposed a formalized procedure for the workspace problem solutions. Even in other steps of the processes, the procedures that have been identified as the most successful had been the ones that results as predefined and validated. Solutions should less rely on personal decisions of project managers and on their skills.
- *Global understanding*. Even encouraging the development of predefined processes and automation in managing data, this review suggests that a global and incisive understanding of the entire process should always been maintained. Data should be analyzed and understood completely through human critique skills. This will avoid definition of unrealistic problems and will lead to consider their criticism level.

If all those elements will be taking into account in further studies, efficiency in workspace planning will increase.

4 Summary

In this review recent progress regarding workspace planning process was analyzed and ranked according to which are the elements can make the process more efficient. The review suggests that further studies in this area should be focused on the creation of intelligent 4D databases and easier tools to manage workspaces. The review also suggested that there is a need for the improvement of resolution strategies when assessing workspace problems.

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