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A LITERATURE REVIEW ON 4D BIM FOR LOGISTICS OPERATIONS AND WORKSPACE MANAGEMENT

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ABSTRACT

Planning the logistic operations and the construction site layout is extremely important to avoid waiting time, double handling, transportation wastes and workflow conflict. Therefore, workspace management can support the Lean thinking through minimization or even completely eliminating the transportation, inventory and motion tasks, which are all non-value adding activities. In fact, much has been written on ways to minimize site logistics waste but few studies have addressed the use of 4D BIM for logistic operations and transportation waste reduction on jobsites. This paper presents a literature review of mainstream studies of 4D BIM, focusing on logistic operations in order to identify study opportunities for waste minimization in workspaces and workflows. The methodology employed is based on a review of the literature published in the last 10 years, in which information was collected from the International Conference of Lean Construction (IGLC) papers and a set of mainstream computing in civil and building engineering journals. This paper aims to contribute by providing a state of art on 4D BIM for site layout planning and workspace management for this knowledge area.

KEYWORDS

Building Information Modeling (BIM), 4D modeling, logistics and workspace.

INTRODUCTION

Nowadays, the construction industry is growing in size and complexity. Some issues such as lack of workspace, concurrent and constrained areas and poor workspace planning cause significant loss of time and money in a construction project (Moon et al. 2014). These problems are closely related to the construction logistic operations planning.

Construction logistics include the planning, execution, steering, documentation and the monitoring of all projects related to the flows with regard to materials, people, space and information (Lange and Schiling 2015). The term flow has some important intuitive qualities, such as a chain of events (sequence), continuous movement, moving freely, and

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adding value (Pérez et al. 2014). In logistics, Jongeling and Olofsson (2007) define workflow as "the flow of resources through locations". Bowersox and Closs (1996) define material flow as the movement and storage of materials and finished products, and information flow as the identification and specification of different requirements in a logistics system.

On the other hand, the increasing complexity of projects, has increased the developing and usage of Information and Communication Technology (ICT) approaches (Bryde et al. 2012), and following this trend, the expansion of BIM (Building Information Modelling) has been massive in the last decade. BIM can be defined as "a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all design team members to collaborate more accurately and efficiently than using traditional processes" (Lee 2008). Some new concepts and BIM applications have been developed for different purposes in the construction industry, such as 4D, 5D, 6D and 7D dimensions.

Specifically, the aim of 4D BIM models in production planning is to provide a virtual environment for simulating, viewing production processes and operations, and for identification of spatial conflicts that can occur in the three dimensions and across time (Tantisevi and Akinci 2007). Despite the fact that several studies can be found in the literature on 4D modelling application in construction, few of them are related to logistics operations and there is still a lack of a systematic body of knowledge concerning this area. Therefore, this paper presents a literature review of mainstream studies of 4D BIM, focusing on logistics operations, and workspace management published in the last 10 years aiming to explore how the construction management community has approached this virtual environment for waste minimization in workspaces and workflows. According to Pérez et al. (2014), the logistic management is focused on cost reduction, and one way to do that is through the flow management for waste minimization. Therefore, the study of logistics operations will allow to identify opportunities for waste minimization. This paper aims to contribute by providing a state of art on 4D BIM for logistics and workspace management.

RESEARCH METHOD

This study was developed based on a literature review of empirical and theoretical studies already published. Moreover, this study was performed aiming to identify study opportunities for waste minimization in workspaces and workflows through the use of 4D BIM tools.

RESEARCH SOURCES SELECTION

The first stage involved the selection of journals that had within their scope issues related to design, architecture, construction, technology, informatics, and management in order to identify the one most closely related to the field of this study, according to the Table 1.

The proceedings from the International Group of Lean Construction conference from 2005 to 2015 were included as a data source, due to the relationship between logistics and lean construction and its concepts of non-value adding processes and wastes. The understanding of benefits, changes in information and BIM tools themselves and lean construction principles should result in a conceptual understanding of the theory of production in construction (Sacks et al. 2010). Aiming to increase the sample size, oil, gas and rail sectors publications about the theme were searched.

Table 1: List of the selected journals

Journal	Institution
Journal of Architectural Engineering	ASCE
Journal of Construction Engineering and Management	ASCE
Journal of Computing in Civil Engineering	ASCE
Journal of Management in Engineering	ASCE
Advanced Engineering Informatics	ELSEVIER
Automation in Construction	ELSEVIER
International Journal of Design Computing	ELSEVIER
International Journal of Project Management	ELSEVIER
Construction Management and Economics	Taylor and Francis
Journal of Civil Engineering and Management	Taylor and Francis
Journal of Information Technology in Construction	ICRIBC*
Construction Innovation	Emerald Insight
Engineering, Construction and Architectural Management	Emerald Insight
Computer aided Civil and Infrastructure Engineering	Wiley Online Library
International Journal of Architectural Computing	SAGE Journals
Journal of Information Systems and Technology Management	TECSI – USP
Conference Proceedings of IGLC	IGLC
Institution of Civil Engineers	ICE

*International Council for Research and Innovation in Building and Construction

DATA ANALYSIS

A preliminary search of these journals and proceedings was performed to focus on BIM, 4D or/and logistics. Firstly, all articles published in the last ten years were analyzed and the papers that had those words in the title and/or the keywords were selected. Due to the number of papers identified and also because the majority of the articles were related to only one or two of the issues simultaneously, such as BIM and 4D, the data analysis was narrowed down focusing on the application of 4D BIM for logistics, using the three keywords and related keywords BIM, 4D and logistics. However, during this research, a lack of articles specifically about 4D BIM for logistic purposes was possible to identify. Only a few articles had the referred words in the tittle or in the keywords. Therefore, the research was expanded and other keywords related to planning and logistics were also used, such us: layout, transportation management, motion, location, supply chain management, workspace, workflow and space planning.

A total of 20 articles was chosen to be part of this literature review. The Automation in Construction Journal published 9 papers of this sample (47%), and the Journal of Information Technology in Construction published 4 papers (21%). The remaining journals and conference proceedings shared 32% of the articles, according to Figure 1. However, despite the identification of some papers in the oil, gas and rail sectors, only one of them (Li et al. 2013) used 4D BIM with logistics purposes. Figure 2 indicates that the evolution of the number of the articles in years was not significant.

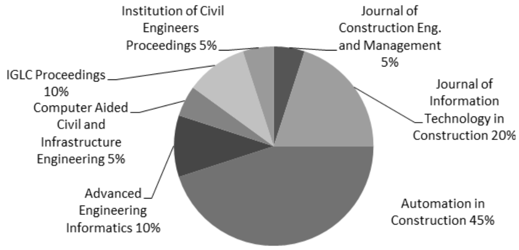

Figure 1: Number of articles founded per journal or proceedings

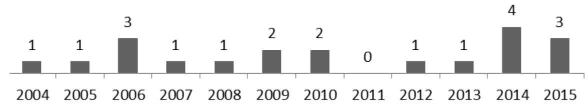

Figure 2: Number of articles by year

STUDIES RELATED TO 4D BIM FOR LOGISTICS PURPOSES

The 20 papers selected were classified according to their main features (see Figure 3). The first classification of the articles was related to the project stage, meaning Design stage (2 papers) and construction stage (18 papers). Then, the papers were classified in terms of spatial conflicts (workspace conflict process) and spatial time conflict (schedule conflict process).

Stage	Dimension	Contribution	Approach	Product	Unit of Analysis	Authors
Design (2)	Spatial-Time (2)	Proposal (1)	Rule-based heuristic strategies (1)	A system framework		Cheng & Kumar 2015
		Analysis (1)	-	Benefits and limitations	Site process	Bortolini et al. 2015
Construction (18)	Spatial-Time (16)	Proposal (11)	Algorithm (3)	Genetic Algorithm (GA)	Interior building space	Mallasi 2009
				Congestion penalty indicator	Oil refinery Reactor Column	Chua et al. 2010
				An optimized algorithm	Express railway project	Moon et al. 2014
			Artificial Intelligence (8)	4D integrated site planning system (4D-ISPS)	Building and jobsite	Ma et al. 2005
				Visual Planning tool	Jobsite	Dawood et al. 2005
				Software tool	Workspace	Riendau 2006
				Visual Planning tool	Jobsite	Dawood& Mallasi 2006
				A concept for visualizing workspace competition	Workspace	Mallasi 2006
				The intersection test	Workspace	Chavada 2012
				A bounding box model and an algorithm	cable-stayed bridge project	Moon et al. 2014 (P17)
				A holistic solution for workspace management	Workspace	Kassem et al. 2015
		Analysis (5)	-	The use a combined method to plan workflow	Workflow	Jongeling & Olofsson 2007
			-	3 types of analyses: (workflow + planning of temporary structures + productivity)	Workflow	Jongeling et al. 2008
			-	A tool to System evaluation, Usabil ity study, and Management plan	Workflow Construction project	Tsai et al. 2010
			-	A construction model	Site Layout	Li et al. 2013
			-	A 3 comparative analysis of layout(static + phased +dynamic site layout planning)	Site layout	Andayes & Sadeghpour 2014
	Spatial (2)	Proposal (2)	Rule-based heuristic strategies (1)	A 4D product and a process model	Crane location	Tantisevi & Akinci 2007
			Algorithm (1)	Geometrical approach	Crane location	Tantisevi & Akinci 2009

*Number in brackets indicates the number of papers in each section

Figure 3: Papers classification according to their features

At the Design stage both papers were related to spatial-time conflicts. For example, Cheng and Kumar (2015) established a rule-based heuristic strategy and Bortolini et al. (2015) analyzed the benefits and limitation of the use of 4D for logistics to improve the performance of the site assembly process. For the construction stage, the highest number of articles is related to the spatial-time conflict detection (16), space conflicts appear only in 2 articles. In terms of spatial-time conflicts Mallasi (2009), Chua et al. (2010) and Moon et al. (2014) proposed different algorithms. Artificial Intelligence is the approach used by some authors (Ma et al. 2005; Dawood et al. 2005; Riendau 2006; Dawood and Mallasi 2006; Mallasi 2006; Cahavada et al. 2012, Moon et al. 2014, Kassem et al. 2015) to identify schedule and workspace conflicts. In addition, in terms of spatial conflict detection Tantisevi and Akinci (2007; 2009) proposed a rule-based heuristic strategy and an algorithm respectively to model workspaces of mobile cranes.

DESIGN STAGE

Two articles (Cheng and Kumar 2015, Bortolini et al. 2015) were performed during the design stage and both of them deal with layout planning on an operational level.

Cheng and Kumar (2015) state that layout planning should be carried out not just on a strategic and tactical level, but also on an operational level in order to ensure a smooth workflow. Bortolini et al. (2015) agree about the necessity to model critical logistics operations with a fine level of detail. According to Bortolini et al. (2015) through 4D simulation, the times of each process involved could be analyzed in detail and thereby increases the assembly productivity, reducing inventories and work in progress and seeking a continuous flow of production. The simulation of the activities on an operational level means simulating both value-adding and non value-adding activities (Bortoloni et al. 2015).

However, according to Cheng and Kumar (2015), managing the layout planning on an operational level has certain limitations, such as: (1) the level of development of the BIM model should match the level of detail in the construction schedule, (2) the reporting of construction progress and amount of materials used would have to be performed frequently, (3) the presence of buffer zones is not taken into account, and (4) the supplier has to update the date when the material is ready to dispatch and dispatched.

CONSTRUCTION STAGE

Most previous studies on the use of 4D BIM model during the construction stage for logistics can be classified according to their focus on the conflict detention.

Spatial and time conflict detention

Most of the papers related to space-time confliction detection mentioned the Critical Path Method (CPM). In fact, most studies on 4D models are simply a translation of the output of a CPM network that contains only transformation activities. It implies that the so-called flow activities are being neglected once more (Bortolini et al. 2015)

A) Algorithm Proposal

Different authors (Mallasi 2009; Chua et al. 2010; Mon et al. 2014) analyzed the conflict and congestion at the workspace and schedule dimension, conceiving the idea of utilization. As a result, those authors proposed algorithms for quantifying space and time congestion at jobsite.

Chua et al. (2010) described the concept of utilization as a measure of how much a resource is put in use through the concept of space demand and supply. In this same vein, Mallasi (2009) compares the workspace with the approach of 'cutting 2D-shaped parts from 2D metal sheets with minimum wastage of material'. The material waste (area utilisation) is minimised by Genetic Algorithm (GA) searching for the optimum utilisation of sheet area. The case is similar to reducing the site space-usage occupied by the activities' execution workspaces'.

According to Chavada (2012) the workspace can be divided into the following categories: (a) main workspace (associated with value added activities); (b) support workspace (associated with non-value added activities); (c) object workspace (considered permanent space, once built by an activity and it covers all building objects); and (d) safety workspace (area that allows a tolerance between two workspaces to prevent safety hazards). The workspace categories proposed by Chavada (2012) were used as a basis for the identification of them in the three studies which proposed an algorithm approach (Table 2).

The classification of workspace from the studies indicates the construction process and the object that they will accommodate, but to identify the potential features needed for congestion minimizationthe workspace should also have in its project plan information related to the activities that will be accommodated.

Table 2: Workspace type classifications

Workspace	**Mallasi (2009)**	**Chua et al. (2010)**	**Moon et al. (2014)**
Main workspace	Process space	Process space	Installation space
Support workspace	Equipment path	Interdiction[1] Space	Transfer space
	Support space	Dead space	Loading space
	Path space	Resource handling space	
Object workspace	Product space	Product space	Prefabrication space
	Workspace		
	Equipment space		
	Storage path		
Safety workspace			Safety space

*Adapted from Chavada (2012)

B) Artificial Intelligence Proposal

Of the 19 papers studied, 7 used Artificial Intelligence (AI) to plan workspace, meaning that they investigated the generation, allocation, conflict detection and conflict resolution at workspaces with the use of an Industry Foundation Class (IFC) tool.

Ma et al. (2005) introduce a 4D Integrated Site Planning System (4D-ISPS) which integrates schedules, 3D models, resources and site spaces together to provide 4D graphical visualization capability for construction site planning. Riendau (2006) proposed a software tool which follows the various versions of a project, creating a new set of files that are interconnected and produce a 4D interface to navigate through these files. Dawood et al. (2005), Mallasi (2006) and Dawood and Mallasi (2006) introduced the

[1] Interdiction spaces are spaces where no product, process, or resource is allowed to occupy, and are typically specified for reasons of hazards or protection

Critical Space-Time Analysis (CSA), a concept to quantify the congestion degree between the overlapping workspaces, and to visualize workspace congestions in architectural projects. Moon et al. (2014) suggested an optimized algorithm based on a location-constraint GA that can minimize workspace interference. Kassem et al. (2015) present the results from the development and evaluation of a methodology and an Industry Foundation Class (IFC) compliant 4D tool for workspace management. Chavada (2012) presents a novel approach for the management of AEWs. by integrating the traditional planning process (CPM) and BIM data in a 4D/5D environment and providing real-time management and rehearsal of AEWs. Table 3 sums up the category of papers.

Table 3: Main focus of the papers which used AI to study workspace

Workspace aspect studied	**Ma et al. (2005)**	**Riendau (2006)**	**Dawood et al. (2005)/ Dawood and Mallasi (2006)/ Mallasi (2006)**	**Chavada et al. (2012)**	**Moon et al. (2014)**	**Kassem et al. (2015)**
Generation	X		X	X	X	X
Allocation		X	X	X	X	X
Conflict detection			X	X	X	X
Conflict resolution				X		X

Most of the studies presented in this section were focussed on workspace generation, allocation and conflict detection. However, the effort to resolve conflicts in order to optimise workspace utilization in the workflow is relative small.

C) Analysis

A set of papers among the reviewed papers performed an analysis of the use of 4D BIM (Jongeling and Olofsson 2007, Jongeling et al. 2008, Tsai et al. 2010, Li et al. 2013, Andayesh and Sadesghpour 2014). However, only Li et al. 2013 and only Andayesh and Sadesghpour (2014) focused their analysis on logistics purposes. Jongeling and Olofsson 2007, Jongeling et al. (2008) and Tsai et al. (2010) are more interested in understanding the workflow.

Jongeling and Olofsson (2007) present a method for the planning the workflow by combined use of location-based scheduling, such the LOB scheduling technique, and 4D CAD. The case study presented by Jongeling and Olofsson (2007) is limited to the planning for workflow and does not address the control of workflow. Jongeling et al. (2008) show how different types of 4D content can be extracted from 4D models to support 4D-content-based analyses and novel presentation of construction planning information. Tsai et al. (2010) presented a framework to assist the introduction of a 4D tool for consulting firms that have large organizational structures and well-established workflows.

Li et al. (2013) present a construction model, which was developed from design model and linked to the construction programme. The 4D model included temporary site components and the traffic access routes for vehicles and people. As the logistics plans need to be reviewed in a daily basis in order to reflect the changes on site, a computer program was developed.

Andayesh and Sadesghpour (2014) state that traditional approaches related to site layout planning have focused on static layout or dynamic in terms of change layout according to the construction. However, those authors argue that within the approaches that were previously grouped under the general term “dynamic layout planning”, there are in fact two distinct approaches of phased and dynamic layout planning. The phased approach proposed by Andayesh and Sadesghpour (2014) offers an improvement over the static approach in terms of over-allocation of the space. However, since it does not reflect the changes within each phase, it still does not allow for the most efficient use of site space in the final layout.

Thus, the main contributions of the papers presented in this section are related to the study of the time and duration of construction objects (equipment, materials and workspaces) on the jobsite. Therefore, scheduling opportunities should be identified during workflow and layout planning in order to minimize the waste of time, waiting by crews, rework and disruptions.

Space conflict detention

Two papers (Tantisevi and Akinci 2007, 2009) used 4D BIM without considering the schedule in their analysis. Tantisevi and Akinci (2007) proposed an approach for generating workspaces that encapsulate spaces occupied by mobile cranes moving during an operation. Tantisevi and Akinci (2009) expand the representation of cranes implemented in Tantisevi and Akinci (2007) and other previous approaches to incorporate functional information, such as lifting. According to the authors, functional representation illustrates the design intent of cranes and describes how they should be expected to behave under different operating conditions. The output of the approach of Tantisevi and Akinci (2009) is a 4D model, which includes construction processes described in multiple levels of detail. The geometric transformations generated by this approach can be used to model workspaces of mobile cranes to identify spatial conflicts and determine conflict free locations for mobile cranes.

In these studies, crane operation was decomposed into small motions that are composed of a sequence of geometric transformations. Similarly, 3D model should be divided in multiple levels of detail in order to be used as the basis for the visualization, the modelling workspaces, identification of possible spatial conflicts.

CONCLUSIONS

Numerous studies related to BIM including 4D CAD have been performed, particularly in the area of work schedule, workspace interference and conflict detection. The literature review performed indicated that the number of papers focused on how 4D BIM has been used for logistics purposes in building environment is relatively limited because its application is fairly new. The fact of having enlarged the initial search with other words, such us: supply chain management, space planning, workspace and workflow deviated from the main objective of this literature review. Most of the papers found with the keywords were related with three main elements: generation and allocation of workspaces, detection of congestion and spatial-temporal conflicts, and the resolution of identified conflicts.

Some studies (Bortolini et al. 2015; Cheng and Kumar 2015) pointed out the benefits of using 4D BIM to help in daily operational decisions that do not adhere to the original layout plan. This is based on the idea that the lack of site layout planning at an operational level generates most of the daily layout problems at the jobsite. In fact, some papers have pointed to the need to perform further studies at the operative level approach in order to study the movement and workflows of workforce at jobsites. Despite 4D models have been used at oil and gas sector for several years, the main applications were related to the identification of conflicts among components.

However, planning of workflow with a 4D BIM model requires additional objects that are not included in most of today's 3D building models, because most 3D models are limited to building components (Jongeling and Olofsson 2007). Thus, space should be considered as a resource that is related to a location and a task in a project for the planning of workflow. The Line of Balance (LOB) technique is pointed out by some authors (Jongeling and Olofsson 2007, Bortolini et al. 2015) as a useful mechanism to achieve that, due to the fact that 4D BIM tools, combined with LOB, could facilitate logistics planning.

The main contribution of this paper is to highlight the main uses of 4D BIM by the construction management community in the last ten years for logistics purposes. Further studies focusing on workflows are necessary to reduce daily logistics problems at jobsites.

In addition, 4D building models need to be organized according to a location-based logic, avoiding workflow conflicts. For that, 3D CAD building components should be linked with the schedule of the tasks. Those linkages could potentially allow the detection of the congestion and the spatial–temporal conflicts between workspaces. However, there is no commercial software that offers this sort of function. Moreover, 4D models need to be updated frequently, since the amount of information used varies according to the requirements of each project, and once again, there is no commercial software for automatically updates. Moreover, this literature review allows the authors to understand the main uses of 4D BIM for layout management area and to identify study opportunities for conflicts minimization in workspaces and workflows from the introduction of traffic access routes for vehicles and pedestrian into the model.

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