Integrated Digital and Model-Based Construction Logistics Management Based on Lean Thinking Approaches

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Abstract –

As an elementary part of building projects, construction logistics encompasses planning, control and monitoring functions to ensure the flow of materials and people on the construction site. Furthermore, it includes the management of storage areas and site facility planning. Despite its importance, the implementation of construction logistics often does not occur systematically. In practice, the project phases in which its planning and implementation take place as well as the considered degrees of detail differ significantly depending on the project conditions, such as the projects' complexity, involved stakeholders or the scope of the construction project.

In this paper an approach is presented that facilitates a systematic and holistic planning of construction logistics over all project phases on basis of lean construction principles. To achieve this, the coordination of all domain-specific stakeholders (e. g. construction logistics planners, site managers, contractors) is essential. As a work basis, construction logistics planners can create a specific digital construction logistics model (CLM) derived from the digital architectural model. This CLM can be used to schedule deliveries and storage areas, as well as logistics related information (e.g., delivery dates, storage areas, escape routes, waste collection points or construction site equipment elements).

Construction logistics has to be generally accepted as an own domain-specific role during and especially in the beginning of construction projects to ensure the regarding of all necessary processes and requirements towards the construction logistics.

Keywords –

BIM; Construction Logistics; Domain-Specific Model; Lean Construction; Lean Logistics;

1 Introduction

A way to optimize processes is to use the methods and tools of the Lean Thinking (LT) approach. Their application allows the optimization of processes aiming at minimizing waste and increasing efficiency. By this approach, an optimally use of resources is facilitated. In order to switch from the conventional to a LT-based working method, an analysis of the processes as well as economic and technological aspects have to be carried out first. The approach of adapting LT methods to the construction industry has been investigated since the early 1990s. For this purpose, the International Group for Lean Construction (IGLC) was founded in 1993 [9]. Although this process of implementing LT in the construction sector has been going on for nearly 30 years, it is only applied in a minority of projects. Recent studies pointed out that the application of the Building Information Modeling (BIM) methodology can facilitate the implementation of Lean Construction (LC). The thereby rising synergies can lead to the generation of a significant additional value [13].

This paper examines the construction logistics as one crucial part of construction projects in the context of the interaction between BIM and LC. It is based on the results of a master thesis [10] written at the Institute of Numerical Methods and Informatics in Civil Engineering (IIB) at Technische Universität Darmstadt. It forms a starting point for further research. The overall goal of this future work is to investigate how the holistic integration and linkage of both approaches over all project phases can improve the projects' results as well as facilitate a more cooperative way of interaction between all stakeholders.

Due to the high demands towards construction logistics, construction projects in densely built-up areas are regarded as a field of application; Resulting constraints are, for example, the limited amount of space available inside and outside of buildings or the tense traffic situation in the surrounding area of the building site. According to [17] "Interruptions caused by breakdowns, clean-up and rearrangement, material search, ways and transports" cause a share on all activities of 33.4%. Optimization of construction logistics can thus contribute to cost reduction, improved adherence to deadlines and, in general, to improving the organization of construction sites.

2 State of the Art

2.1 Building Information Modeling

The Building Information Modeling methodology is applied more and more frequently in construction projects. Furthermore, steps towards the implementation of a legal framework for the public sector in Germany are made. According to [6], BIM should be considered and applied in all public infrastructure projects in Germany from 2020 on. Pilot projects, such as mentioned in [16], have already been planned and implemented according to this methodology. As one main type of output of the BIM methodology building models serve the purpose of digital information management on which, for example, simulations, clash detection checks (between specific domain models) or visualizations can be performed.

On the part of the executing companies, the benefits of this methodology are increasingly recognized (in particular as a data basis for later operation, e.g., Facility Management) and specialized working groups are set up in companies like Strabag, Hochtief or Zechbau. By linking to tendering programs or scheduling software the automation of processes is facilitated and thereby quality can be improved and costs reduced.

2.2 Domain Models and Level of Development

In literature, several concepts to define and classify domain-specific models are outlined. According to [12], a domain-specific partial model is a trades-specific model that contains all information provided and required by a planner. These sub-models can serve, for example, as basis for the coordination of issues regarding different trades like clash detection issues. Depending on the stored information, a distinction is made between the BIM dimensions 3D (geometrical data), 4D (3D + Dates), 5D (4D + Costs), 6D (5D + Life Cycle Data) and 7D (6D + Facility Management Data). In general, these models can be understood as nD-models which can be extended by any kind of information needed within a specific domain or project. [2] states that sub-models differ in their domain (specialist perspective), zones (spacial structure), degree of detail and phases (period of observation). In this paper, a domain-specific model is classified according to the requirements defined in [15]. It distinguishes between Level of Geometry (LoG), Level of Information (LoI), Level of Coordination (LoC) and Level of Logistics (LoL). In the following, the contents of a specialized Construction Logistics Model (CLM) are described in more detail on the basis of the LoL. The LoL reflects the spatial and temporal development level of the logistics processes. All components of the digital building model are put in a temporal and local context with regard to their delivery to the site and their assembly.

2.3 Lean Thinking

One approach to optimize processes and thereby workflows is the adoption of Lean Thinking - including the underlying principles and tools - to the construction industry, known as Lean Construction. LC focuses on the value created from the perspective of the client; by means of continuous optimization and the reduction of waste, the proportion of value-adding activities is to be maximized.

Lean ideas have so far not been applied uniformly to building projects. A major problem with current construction projects is still the waste of various resources and their uneconomical handling. Nonetheless, there are examples from the residential and office construction sector in which the use of lean methods (Takt planning, Takt control, process optimization) led to the minimization of waste and an increase of the cost-effectiveness [7].

2.4 Construction Logistics

Construction logistics as an integral part of the value chain of construction projects must be planned, controlled and managed carefully. In the implementation of large-scale projects, it is already frequently involved in early project phases [16]. In small and medium-scale construction projects, on the other hand, it is often not taken into account until late or even not at all. In contrast to other disciplines, it is not always perceived as an important and independent component of construction projects.

This so far low prioritization of construction logistics, but also its increasing importance, is reflected in the German Official Scale of Fees for Services by Architects and Engineers (Honorarordnung für Architekten und Ingenieure, HOAI), for example. Until 2011, there was no basis for billing the services of construction logistics in Germany, as the HOAI does not include a service profile for the technical planning of construction logistics. This was first made possible by the introduction of [1].

3 Building Information Modeling and Lean Thinking

As recent researches show, overlaps between the two approaches of Building Information Modeling and Lean Thinking can be found on various tiers. Figure 1 illustrates an excerpt of them. Synergies arise which can lead to improvements in a variety of use cases [14].

On an abstract level, both approaches contain principles that complement and can be combined with each other. At the company level, tactical management must already work towards implementing both approaches throughout the company. There are also major overlaps in the objectives of BIM and LT.

At the operational level, project management based on LT and using the BIM methodology must be implemented. Practically, this can be done with different tools. The concept of the Lean Construction Logistics Management, described in the following chapters, covers one part of this topic. Further information and general considerations on the linkage of BIM and LT and the resulting increase in value in construction processes can be found, e. g., in [11], [5], [13] or [3]. Most of recent studies are focusing on the investigation of these synergies on an abstract and theoretical level. The research at IIB has the goal to investigate approaches that promote a holistic implementation of LC and BIM in practice by the example of construction logistics.

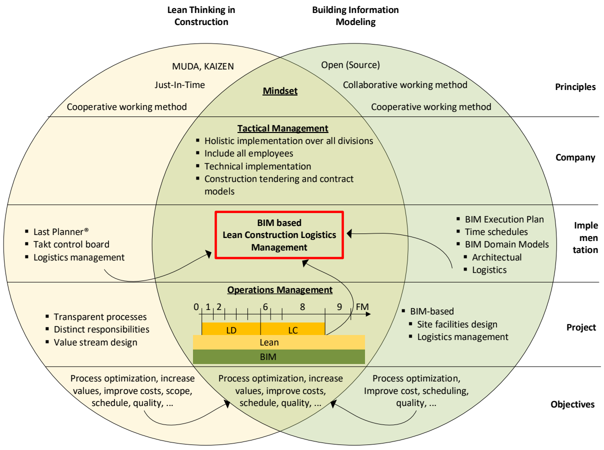

Figure 1. Synergies between Building Information Modeling and Lean Thinking

4 BIM-based Construction Logistics as Part of a Holistic Lean Construction Implementation

For a holistic implementation of the LT approach in construction projects, acceptance by all project participants as well as an implementation in all disciplines and across all project phases is a prerequisite. For this purpose, different tools and methods of LC are suitable.

The types of waste in the construction industry illustrate the importance of construction logistics. For example, the reduction of material stocks, waiting and transit times or the most efficient use of space offer great potential for optimization.

This paper therefore shows an approach for a BIM-based planning and implementation of construction logistics and gives examples for where to increase the value in construction processes in accordance with LC.

4.1 Structural Implementation

Shortly after project initiation, the project management has to consider the role of construction logistics. Only this early integration allows a holistic integration of construction logistics. In addition, all disciplines involved must be taken into account in logistics planning. From the development of the first planning concept and the known constraints, the development of a basic logistics concept can be started. Such a concept must be coordinated with the construction management processes and dependencies as well as with the implementation of LC. It is then worked out and refined over the further project phases.

Construction logistics must also be taken into account in the subsequent project phases. For example, construction logistics services must be subcontracted, which requires a contract specification. In particular, it must define a lean-based implementation. For example, suppliers and contractors need to know that they have to coordinate their production and assembly on site with a clocked schedule and change over to Just-In-Time (JIT) delivery and assembly.

In the execution phase, construction site management must be able to monitor and control the implementation of planning on the construction site. In addition to the implementation of lean methods and tools, a prerequisite for this is the provision of all necessary information.

4.2 Information Management

As in all other spheres of construction projects, comprehensive and well-structured information management is essential for construction logistics. According to the LC approach during all project phases

- the right recipient needs
- the right information
- in the right quality
- at the right time
- in the right scope.

Table 1 gives an overview with examples of information that arise in the context of construction logistics and must be linked to a digital building model. For example, the scope described in [1] can be used as the basis for identifying the relevant information. In section 5, a concept is presented which describes the data storage of all building-related information in a specialized model for construction logistics. Appointments, costs and other types of information (e.g. communication) must be linked to this.

Table 1. Examples of construction logistics specific information according to project phases based on [1]

HOAI phase	Information
1	Available space (property), Transport Connections, Neighbourhood restrictions
3	Building logistics concept: presentation of personnel, machinery, material and waste streams
5	Traffic concept, construction site equipment after construction phases, storage areas for supply and disposal, operating areas

4.3 Logistics Stages and Storage Area Management

Considering construction logistics, it is possible to diversify into the logistics processes up to the construction site (supply logistics), on the construction site (construction site logistics) and away from the construction site (disposal logistics).

The processes up to the construction site include transport, transhipment and storage (TTS). The transport can be optimized, for example, by delivering according to the requirements of the construction site (JIT) and operating interim storage facilities (e.g. logistics hubs).

Logistics away from the construction site consisted mainly of waste disposal processes, since in contrast to stationary industry the distribution of goods is not necessary. Here, new structures are needed on the construction site that enable the waste to be collected and disposed of in an orderly manner. In this way, disposal costs can be reduced, recyclable materials can be reused more efficiently and, in general, the construction site can be kept tidy.

Looking at the logistics processes on the construction site, in addition to receiving and distributing goods, storage area management can be identified as a key competence for a smooth and undisturbed construction progress. Due to limited space on the construction site and in the building itself, these must be planned efficiently and depending on the construction process. For this, detailed phase plans must be worked out, which locate the individual storage areas over the course of the construction process. Additional marking of the storage areas reduces search times and a pre-planned placement of these can reduce travel times. Corresponding requirements for the characteristics of the storage areas must be taken into account in advance. A software concept is presented in section 6.

5 Approach

The approach presented in this paper aims towards the development of an innovative and holistic implementation for planning, controlling and execution of construction logistics over all project phases. Thereby, the early integration of construction logistics in building projects shall be facilitated. As mentioned in chapter 1, in this paper first considerations are presented to serve as a basis for further and more profound research.

The focus lies on a construction logistics model, which is derived from an architectural building model. Besides the geometry and semantics of the underlying model, this CLM encompasses all information concerning construction logistics presented in chapter 5.1. According to the BIM methodology, the CLM must be created in an early project phase and then maintained over all subsequent project phases.

For enabling logistics planners, site managers and suppliers to work with this CLM, a software tool needs to be provided that extends existing software applications. One of its tasks is providing the opportunity to create relations between the building model and the construction logistics schedule. Especially construction site supply and disposal as well as storage and transport operations on the construction site have to be taken into account in this context. This application serves as a central construction logistics information management system and is extended by a digital storage area management.

Figure 2 shows the scope of the concept called Lean Construction Logistics Management (LCLM) introduced in this paper. In the following sections the relations between scheduling, construction logistics and the CLM are presented.

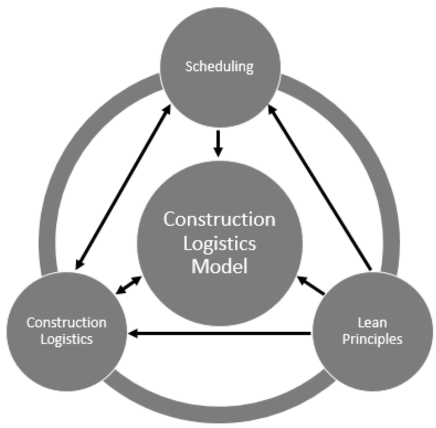

Figure 2. Overview of the LCLM Concept

5.1 Construction Logistics Model

5.1.1 Components

The CLM contains a large amount of geometric and semantic information. Besides the building itself, geometric information include site boundaries, additional floor plan information and object geometries. In addition, the model can have geometric information about the construction site equipment with storage areas, assembly areas and traffic routes. The object geometries include the components to be stored, construction aids and construction equipment.

In addition to these geometric representations and information, various semantic information is necessary for the construction logistics planning. Information about routes, costs and time connections are needed. In addition to construction roads, the routes include pedestrian routes and emergency escape routes. In the inner city environment, the area around the construction project should be included in the logistics planning for delivery. A detailed environment or city model can be used for this purpose. In addition, a logistics hub can be designed in advance if required.

All this information forms the basis for optimizations based on calculations and simulations. For example, the optimization of routes facilitates a reduction of way distances and travel times. Equally, an optimal use of the available space leads to more efficient storage and material distribution and, in general, a tidy construction site.

5.1.2 Requirements

In addition to the geometric and semantic components of the domain-specific model, there are further requirements that are important for construction logistics. For an integral planning of construction logistics, which takes into account the entire progress of the project, it is necessary to link the individual components with the corresponding (logistics) processes from schedule planning. This approach allows the planning to be adapted to the construction process and thus possible conflicts can be avoided.

There are also requirements regarding the information to be stored. These must always be available in the correct level of detail. The most important information includes details on measurements, materials and equipment. The dead weight, transport weight and dimensions are essential. Building geometries and storage areas must also be described in sufficient detail.

Depending on the specialist discipline, other domain-specific models must be included in the planning of construction logistics. For example, geometric framework conditions may exist from the HVAC or carcass construction.

5.1.3 Model Uses

After the comprehensive creation of such a specialized CLM, it can be used in different ways. On the basis of the partial model, collision checks can be carried out with other specialist models in order to detect collision points (paths, areas, dimensions) in planning and to work out countermeasures. Corresponding collision checks on the transport route to the installation site are mandatory.

Furthermore, digital planning methods can be used to carry out a storage area management system that improves the construction process and tidiness on the construction site. Efficient storage space management minimizes travel and search times. The digital planning also enables the control and management of construction logistics. Based on the stored information, a digital construction logistics manual and phase plans can be derived. By linking it to scheduling, simulations can be executed and multiple scenarios evaluated. To examine the flow of goods on the construction site and to control it, the model can be combined with a goods control system, extended by the time component. By using a goods control system, all goods receipts (inbound deliveries) can be checked and logged. This serves for documentation and quality assurance. The use of RFID technology has already proven to be a common practice in (construction) logistics.

5.1.4 Project Context

Information management plays a crucial role in the execution of projects throughout all project phases. In order to ensure a smooth and trouble-free project flow, principles of collaboration and project standards must be agreed upon. As digitalization in the construction industry progresses, contracts must also be adapted and expanded. Common practice is the definition of BIM-related content, such as roles and stakeholders involved, use cases, information exchange, software to be used, etc., in a BIM Execution Plan (BEP). On the part of the client, Employer's Information Requirements (EIRs) are drawn up. These should be laid down as an integral part of the contract between the client and the contractor.

Information generated during the construction process can be classified in accordance with the LoG-I-C-L scheme (see 2.2) [15]. Depending on the scope of the project and the specialist disciplines involved, it is not sufficient to store the construction logistics exclusively by defining a LoL in distributed specialist or domain-specific models. Rather, as explained in the previous sections, a CLM must be created which contains all the information that is directly within the sphere of influence of construction logistics. This domain-specific model must also be unequivocal and completely defined in a BEP, for example, according to the LoG-I-C-L schema. It must be coordinated with all other specialist models.

5.2 Scheduling in the Context of Construction Logistics

Scheduling places the individual work processes in a temporal context and includes the construction logistics processes. The time schedule can be based on the structure as shown in Figure 3.

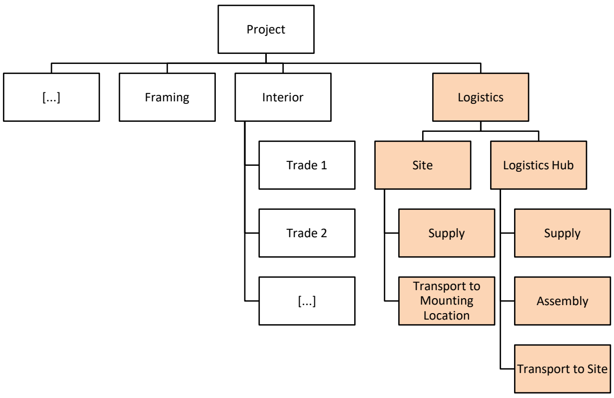

Figure 3. Suggested structure of a construction logistics focused time schedule

One way of classifying the logistics processes is to differentiate them spatially according to construction site and logistics hub, as well as according to their activities in delivery, assembly and transport to the installation location. This structure results from the approach that different stakeholders are responsible for the individual logistics processes. The example structure mentioned above is applicable to all projects with a logistics hub, for example in the inner city area. The structure can be extended to include the provision of construction machinery, taking into account a construction yard. However, the structure can also be reduced by the logistics hub in order to map only the basic logistics processes. It must be adapted to the specific logistical project needs.

5.3 Linkage of Scheduling to the Construction Logistics Model

The connection of scheduling to the CLM can be done, for example, by storing an unique activity identifier on the relevant components. This means that all information is available centrally in the model or is linked to it. The required materials are stored in the schedule as the corresponding resource of the respective operation. By linking the individual processes, interdependencies between building operations are modelled and the execution of construction work is optimized in terms of time. The connection allows a time-dependent observation of construction logistics processes and storage areas in the model.

5.4 Application of Lean Principles

Figure 2 shows that the application of the LC principles influences the scheduling, the CLM and the construction logistics. They are forming the basis for all underlying processes from creation of the first architectural building model to the processes during the execution phase.

The application of lean principles in the construction phase is well known by tools like a Takt Board or principles like Last Planner®. Also in the design phase, the development of a building model can be based on lean ideas. For example, short cyclical design reviews can help to identify issues. Thereby, countermeasures can be taken in an early stage. This approach is called Lean Design (LD) or Lean Design Management.

6 Implementation

6.1 Construction Logistics Model and Time Scheduling

In the following implementation, the specialist model bases on an architectural building model, which contains information on the structural shell and interior finish. The buildings' design follows the LD approach. An architectural model serves as data basis for the developed CLM. Figure 4 shows the floor plan of this model. It consists of four takt sections with the same structure. In addition, the needs of HVAC and other trades must be incorporated into the planning of construction site logistics and, accordingly, into storage area management. This integration will be part of future work.

The shown example building is a reinforced concrete skeleton construction with a steel-glass curtain wall and interior walls made of plasterboard. The elevator and staircase cores are made of in-situ concrete.

Autodesk Revit software was used for modeling. Each object has a comment field within its properties. The connection to a testing schedule is implemented in this module. The comment field is used to include the operation IDs from the testing schedule. In this way, a component can be assigned to several processes. The information of the activities can be accessed via the stored IDs of the processes in the CLM. This enables a time-dependent space management straight from within the CLM.

Furthermore, the model also includes an outsourced logistics hub and the transshipment point on the construction site. The placement of the logistics hub is not geographically correct in the context of site supply, but serves to visualize the TTS processes. The core components of the model are therefore:

- Geometric and semantic representation of
    - Storage areas
    - Ground plans and terrain model
    - Objects to be stored (building materials, components, auxiliary equipment, etc.)
    - Logistics hub
    - Construction site equipment incl. transshipment point
- Linkage of the detailed time schedule for execution and a derived time schedule of the construction logistics
- Different model versions depending on the project phase with the right information content (LoG, LoI, LoC, LoL)

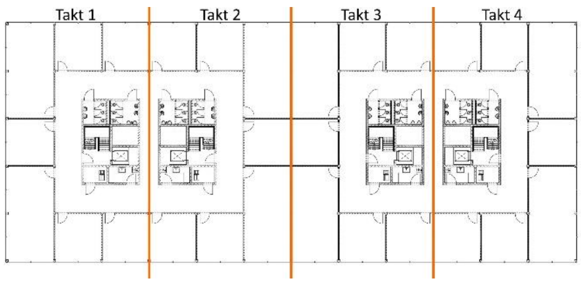

Figure 4. Floor plan showing four takt sections

The time scheduling is structured according to the structure shown in the section 5.2. It is designed in a high level of detail so that it can be used to control the construction progress during the execution phase.

6.2 Lean Construction Logistics Management

Based on Autodesk Revit, an AddIn was created that includes an interface to time scheduling and enables the creation and administration of storage areas. LCLM essentially comprises the following functionalities:

- Linking of tasks from a schedule to components
- Placing storage areas in the floor plan
    - Manually by user
    - Automatically by an algorithm
- Displaying Information about storage areas
- Generate target/actual comparisons with regard to the material delivery
- Display material and components of an operation in the model
- Simulation and visualization of the construction process

6.3 Limitations

There are proprietary software tools available for linking digital building models with time schedules and further information sources (e. g. Autodesk Navisworks, RIB iTWO or ceapoint desite MD). These were not discussed in this paper as well as in the underlying Master's Thesis [10], because the software to use was restricted to Autodesk Revit, Microsoft Project and non-proprietary libraries, like MPJX. Furthermore, a detailed classification in the overall project context becomes part of further research.

7 Conclusion and Outlook

7.1 Conclusion

This paper introduces an approach that puts construction logistics more firmly into the focus of the entire construction process. The role of logistics planning is already taken into account in selected (major) projects. The CLM supports and simplifies logistics planning. Thus, it also promotes the integration of construction logistics for smaller-scale projects.

In contrast to previous approaches, in which only 3D or 4D models are created, the presented construction logistics domain-specific model is integrated into the entire BIM process and not only as a side product, which does not interact with other specialized models and from which no information is returned. By integrating a LoL in all other domain-specific models, the relevant logistics information from these models is also taken into account. The CLM is used for the data storage of building-related logistics information and is linked to schedule planning via software. For this purpose, an AddIn was developed which allows the assignment of processes directly in Autodesk Revit. The basis for this tool is the application of LC, which aims to reduce waste in all processes of planning and execution of the construction project. The presented software supports this by optimizing transport routes and modelling objects of construction logistics, such as storage areas or construction materials.

7.2 Outlook

The approaches and ideas presented in this paper must be further elaborated and examined. The effort required for the creation and maintenance of a construction logistics domain-specific model over all project phases must be determined based on practical examples. In this way, the added value of the described approach can be proven.

On a superordinate level, new ways of thinking must be accepted and applied in the construction industry. In addition new cooperative contract and business models must be promoted, which already build on Lean Thinking and the BIM methodology from the beginning of the project.

Acknowledgement

This work is based on the results of a Master's Thesis at TU Darmstadt's Institute of Numerical Methods and Informatics in Civil Engineering [10].

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