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Improving the Information Flow in the Construction Phase of a Construction Project

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Abstract

In a company and project level it has been noticed that the fluent flow of information will be an essential part of streamlined processes. In the construction phase of a construction project, the information transfers between numerous parties, via different platforms and between people and systems. As the information field in the construction business is highly dispersed, managing the information flow within it is important in terms of efficient workflows.

The study focuses on the problems perceived in the flow of information and the methods of improving the information flow with Lean and Building Information Modeling (BIM) in the construction phase. The study consists of a literature research and an empirical section, which is conducted as a case study. The data collection methods used in the case study are interviews, documents and direct observations made by the researcher. The results of the case study are analyzed and compared with literature findings. There are three cases from different construction phases and altogether six site managers and engineers from the case company are interviewed.

The case study indicates that the element fabrication schedule and manufacturing status of prefabricated elements is prone to change during the project and thus cause a need for a change to the construction process and management. Therefore, it is beneficial that the latency of information regarding prefabricated elements is cut down to minutes instead of hours or even days. As a result, the information flow in the construction phase can be improved especially by 4D scheduling with the use of Last Planner System, the visualization of digital assembly and schedule information in BIM environment and the integration with the Enterprise Resource Planning (ERP) system of prefabrication suppliers.

Keywords: building information modeling, information flow, last planner, lean

1. Introduction and theoretical background

1.1. Information flow

Information flow is required to transfer information between the transmitter and the receiver. It represents the information moving between different parties. Information can be transferred for instance by communication via cell phones or face-to-face conversations, documents or digital information between different systems. The parties of information flow can be humans, systems or a mixed combination of those. It can be either one-way or two-way flow meaning that the information can flow in one or both directions.

In company and project level, information flow has been noticed to be an essential part in developing streamlined processes. One of the common problems within organizations is that the information does not reach the right subject. In addition to that, even if the information is available at the right time at the right place, it is not necessarily efficiently accessible and flawless, since information tends to distort as it flows through multiple parties[1]

In construction business, smooth information flow is important on sites that have a constant need for communication between main contractor, site foremen, project management, subcontractors, designers, prefabricated building element suppliers and other material suppliers. The research made by The Box [2] indicates that the information economy is significantly more shattered in construction business compared to manufacturing, software or media and entertainment industry. Mukaddes et al. [3] see the information flow as the enabler of product flows and thus is in an important role in terms of functionality and controlling the whole.

Information flow is increasingly based on digital data transmission. That means that for instance a paper document based data transmission is decreasing in numerous industries as digital data transmission is significantly faster and safer way to share information to other people and organizations [3]. In the construction industry, this trend is not as strong as in other industries and especially site operations are still strongly based on paper documents [4]

Demian and Walters [5] reported test results of the flow of information using four information systems including e-mail, a construction project extranet tool, an Enterprise Resource Planning (ERP) system and a Building Information Modeling (BIM) system. Albeit the number of projects was small the results showed that BIM foster accurate, on-time and appropriate exchange of information between parties involved in projects.

Harstad et al. [6] researched the use of mobile devices as a method to improve information flow in construction projects. According to the study, existing technology reduces information outages and loss of information in projects. The use of mobile devices improves the information flow between designers and contractors and reduces waste caused by construction works executed using faulty information.

Zeng, König and Teizer [7] reported that BIM based planning of material deliveries is worthwhile as it enables more real-time and solid knowledge to support decisions. In addition to that, the use of BIM did not disturb the normal operation of the site organization.

1.2. Lean construction

Lean is based on a thought of doing more with less. In practice, this means that every resource, such as labor, equipment, time and space are used to increase the value of the product. In addition to that, supporting activities are identified [8]. If the resources do not produce added value, they are considered as waste (often referred with a Japanese word *muda*) [9].

Manufacturing industries have been utilizing lean philosophy for a while. Womack, Jones and Roos [10] and Womack and Jones [11] researched the development of Japanese car industry and came up with the term lean. The philosophy is based on production methods developed by Toyota's executives Taiichi Ohno and Eiji Toyoda.

One of the main principles of lean is the use of methods that improve the efficiency [12] without damaging the quality of the final product [13]. Continuous improvement [13], Just in Time (JIT) production and deliveries [14] and the use of Last Planner System [15] is strongly related to that. It means that the production process is constantly improved based on experiences on the subject.

Even though lean philosophy originates from the manufacturing industry, it is not only applicable in factories. The whole philosophy can also be adapted to other industries, such as highly project-based construction industry. The same methods can not be always used so there is a need to modify the methods to use the philosophy in the construction industry.

1.3. Building information modeling

Building Information Modeling is a whole containing information about the building, its life cycle, production process and other related subjects. The exact definition of BIM has been discussed widely, but there is a consensus that it describes the change from using analog tools to the use of digital tools. [16] Laiserin describes BIM as "a process of representation, which creates and maintains multidimensional, data-rich views throughout a project lifecycle to support communication (sharing data); collaboration (acting on shared data); simulation (using data for prediction); and optimization (using feedback to improve design, documentation and delivery)" [16].

Building information models consist of components, such as windows, doors, walls, slabs, stairs, ducts, pipes, cable trays, piles et cetera. A varying amount of information about the object's properties can be included in the model. To get a comprehensive insight about the building, at least architectural, structural, HVAC and electrical models have to be available. A federated model is created from these separate models to present them as one unified model. [17]

The building information model can be seen as a database of the building since it enables all kinds of information, such as 2D drawings, 3D representations, quantities, measurements et cetera to be taken from the same database. Since all the information derives from the same database, clashes between different representations are eliminated. When an update is conducted, the information can be updated to all documents that are derived from the model. The building information model can cover the project data from planning to construction, operation, maintaining and demolition. [18]

1.4. The interactions between Lean construction and BIM

Sacks et al. [19] have researched the interactions between BIM and Lean construction. In the study, 24 Lean principles and 18 BIM operations were examined and altogether 56 interactions were found of which 52 were positive interactions. 29 of these interactions are related to information flow and 23 of them are present in the construction phase of a construction project. A majority of these interactions seem to affect other interactions as well through the improved information flow.

Sacks et al. [19] and Fosse, Ballard and Fischer [20] concluded that lean principles and BIM had a strong connection. That is why BIM needs to be utilized when implementing lean principles in the construction industry. BIM covers wholes that are connected to data transmission, so it should be utilized in controlling and improving the information flow.

2. Research objectives and methodology

The objective of this research was to clarify how information flow could be improved at the construction phase using Lean construction methods and BIM as an intensifying technology. Based on the literature search the researchers defined the characteristics of a good information flow by the following criteria. A good information flow:

- Is easily and efficiently available,
- Contains high quality and flawless information,
- Is up-to-date and timeliness,
- Reaches the right subject,
- Is in digital format, and
- Utilizes BIM, mobile devices and applications to share information.

Then the researchers propose the hypothesis of dependencies and interconnections with Lean construction methods, BIM and the characteristics of a good information flow. The hypothesis of the dependence between methods used to improve the flow of information is presented in Table 1.

Table 1. Hypothetic dependencies between methods and characteristics of good information flow.

		Easy and efficient access	High quality and accuracy	Timeliness	Reaching the right subject
Lean	Last Planner	Improved	Improved	Improved	Improved
	JIT	---	---	Improved	Improved
	Visual Management	Improved	Improved	---	---
BIM	Design information availability on-site	Improved	Improved	---	Improved
	Quantity take-off and procurement	Improved	Improved	---	---
	4D scheduling and actual progress control	Improved	Improved	Improved	---
	BIM order and assembly visualization	Improved	---	---	Improved

The first author worked as a Chief Digital Construction Officer in the back office of a construction company and the second author worked as a BIM Coordinator in building projects making his master's thesis at the same time. The basic information of cases is presented in Table 2 The progress of the study is shown in Fig 1.

Table 2. The basic information of cases .

Case	Building type	Information flow research subject	Data collection methods
1	Residential	Scheduling	Two interviews, empirical observation
2	Commercial & residential	Precast element assembly	Two interviews, empirical observation
3	Residential	Precast element orders	Two interviews, empirical observation

A preliminary literature study was carried out to get an insight into the relevant temporary theoretical background for the definition of research objectives and hypothesis. An empirical study in three cases was carried out by using action research approach with interviews. The cases were selected from the ongoing BIM projects that have a suitable management system for information flow regarding this research. The second author had an important role observing, interviewing, testing and developing the methods and systems used in the cases. The interviews were executed as semi-structured interviews centralizing in two main themes; information flow and the use of BIM. The interviewer made notes, taped and transcribed the interviews and analyzed the results.

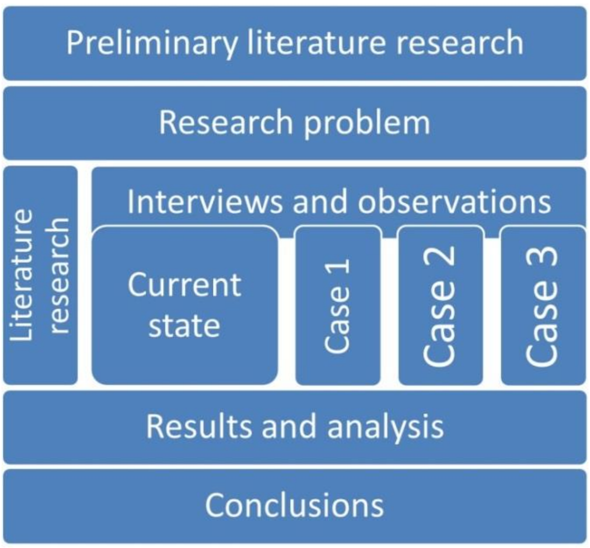

Fig. 1. The progress of the study.

Empirical part was typically a case study research and qualitative research approach was used. A prior understanding of the information flow and its quality factors is formed based on literature study. In practice, the results of each case were compared with the literary definitions of the characteristics of the information flow and the hypothesis whether the information flow has improved on the basis of these definitions. As the researchers compared and analyzed the cases, pattern matching [21] method was used. If the results of the cases corresponded to the expected results, it could be noted that the dependence on the empirically observed factor in the case was strong. Thus, the impact of the methods used in this study on the flow of information could be determined by comparing the effectiveness of information flows with a definitively good flow of information.

3. Results and analysis

3.1. Interviews: Current state of the information flow management on site

The results of interviews and perceptions on site showed that the whole information flow at the site is under the control of the general foreman or the site manager, but the information is transferred between the foremen quite spontaneously. The information flow is strongly based on face-to-face situations and meetings. Each foreman is usually responsible for a certain part of the works on site and maintains the schedules and the information needed in activities themselves. The general foreman or the site engineer keeps a document based or a digital calendar in which all common meetings and personnel holidays are set. Typically, general project information, such as organization charts, general building schedule and contract and procurement information are maintained digitally in the company's project management system or in a digital document store.

At the moment, the design information is generally transferred from the site office to the site using paper documents physically stored in the office or using a digital document store maintained by a service provider and the designers. Some foremen use mobile devices to collect, store and distribute data on site. Emails with attachments and phone calls are used to communicate with designers, subcontractors, material suppliers and engineered to order (ETO) product providers. Site personnel mentioned that the access to the right, accurate and updated design information in the drawings is the most common dispute of information. The lag between the request of information to the time to getting the revised information to site was all too long. Senior foremen felt the flow of information more fluent than junior foremen.

The Lean construction philosophy was poorly understood by the foremen. Junior foremen recognized and explained the core of Lean construction more understandable than senior foremen. Despite the above, the foremen were well aware about Last Planner system and for example the meaning of Big Room. The impact of Last Planner on enhanced information flow and thus better scheduling has been acknowledged.

BIM was familiar to all foremen interviewed, and the foremen said they were using BIM in their work. The 4D schedule was also familiar to almost everyone interviewed. All the interviewees stated that BIM is useful for their work in at least some of the tasks. The main advantage was the ease of visual examination of buildings compared to 2D drawings. In other words, the use of BIM aims to facilitate and benefit the transfer of design information for construction works on the site. For example basic geometrical information and quantities of elements would be needed for the planning of assembly schedule and works. A good 3D site layout facilitates the flow of information of a real-time site situation much easier than 2D drawings.

3.2. Case 1: Information flow on planning and controlling the schedule of frame and finishing works

The project presented in Table 3, the construction phase general schedule was planned using a 2D-based scheduling software by the general foreman. Using that as a starting point, site engineer planned local-based (that is building floors) 4D schedule for construction works including critical path frameworks and finishing works. The finishing works were planned as major activities where the total length of activity was composed of the separate length of the works of sub activities. Activities were connected with the objects in the structural BIM for the simulation and visualization of the schedule. In addition, the schedule included activities without the connection to the BIM objects. Site engineer controlled the progress of activities and wrote back the information in BIM objects visualizing and reporting the progress of activities. The week and location based schedule of finishing works was planned, controlled and maintained using Last Planner system by main and subcontractors. The schedule was located on the wall in the main contractor's' meeting room on site. 4D schedule and BIM model was saved in the main contractor local network and it could not be shared with subcontractors, ETO and material suppliers due to the IT policy and the software version used by the designer.

Table 3. The characteristics of the project in Case 1.

Type of the project	Two identical residential buildings, block of flats, company's own production, Fig. 2 a).
Research subject	Information flow on planning and controlling the schedule of frameworks and finishing
Methods used	Last Planner, Visual Management, 4D scheduling and 3D site layout
Site organization	One general foreman, two foremen and one site engineer
Digital environment	Personal mobile phones, pads and laptops
The knowledge about BIM and Lean methods	Above the average level

During the construction phase, information about time schedules was well managed in the main contractor's organization on site. As well, the information flow between main and subcontractors was well managed in meetings and in Last Planner sessions. The lack of easy and efficient access of 4D schedule was an obvious obstacle to transfer the information to subcontractors on site. The previous was also an issue between the main contractor and designers, material and ETO suppliers. Between the construction parties, the time schedule information was transferred via emails, email attachments and phone calls.

High quality and accuracy of information based on the suitable level of schedule and BIM object content. When using a 4D scheduling too detailed activities and object content to maintain could be an issue, because gathering and writing the progress information in BIM objects takes a lot of site engineer's resources. In this case, the level of 4D schedule and suitable BIM object content was well planned and managed.

The timeliness of 4D schedule depends on the reality of progress information saved in the model. The progress information could be updated without any lag if it is saved immediately after the activity will be finished or, it could be updated once per month before the end of the reporting period. In the case, the progress information was saved daily or weekly and in that way 4D schedule visualized the progress of works on reasonable timeliness.

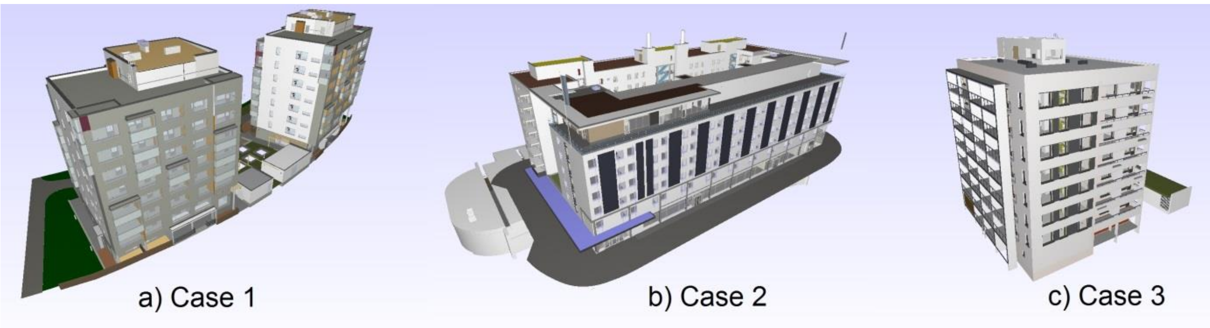

Fig. 2. Cases illustrated

The use of Last Planner suited well to manage the weekly scheduled works between the main and subcontractors. The level of detail of activities was accurate enough. The timeliness of information flow was up-to-date and the information reached all the subjects and parties needed to make decisions in sessions.

3.3. Case 2: Information flow on building element assembly

In the project presented in Table 4,a cloud-based BIM software platform was tested to manage and control the flow of information within site organization for the assemblies of prefabricated and cast-in-place concrete elements, windows and lightweight walls made of prefabricated expanded clay elements.

Table 4. The characteristics of the project in Case 2.

Type of the project	One residential and one commercial accommodation building, block of flats, Fig. 2 b)
Research subject	Information flow on building elements assembly
Methods used	Visual Management and 3D site layout
Site organization	One general foreman, five foremen and one site engineer
Digital environment	Personal mobile phones, pads and laptops
The knowledge about BIM and Lean methods	Average

Building information models and documents were saved in a digital document store for contractors. Main contractor's BIM coordinator integrated architectural, structural and HVAC model as a production model for the controlling of assemblies. Tablet application and laptop software was used to share the model within main and sub contractor organization. The easy and efficient access to the model information was accomplished through the use of cloud-based software platform.

Within sub contractors' organization, there were some interest to use the model but the lack of tablets prevented the active use of the model. The main contractor's site organization used both laptops and tablets to visualize the model and assembly works in the site office. Unfortunately, the foreman in the charge of prefabricate concrete element assembly works could not use any BIM tools to manage the assemblies, and he would not like to cooperate and share information with BIM coordinator. For that reason BIM coordinator was forced to collect controlling information using the BIM software platform on site even the activity was delegated to the foreman. The information flow did not reach right participants in a satisfying way.

Table 5. Status values, their visualizations and interpretations.

Status value	Visualization	Interpretation
None	Grey	No interpretation: Used to cover possible faulty status entries
Started	Orange	Cast-in-place structure is in formwork or rebar phase or expanded clay wall element is installed
Paused	Red	The assembly of the component is paused
Completed	Green	Precast element, window or glass wall is installed; cast-in-place structure is cast or expanded clay wall surface is finished

For the controlling of the phases of assembly works, a work status tool was used in BIM software platform. Several views to the model were planned and saved beforehand in the platform by the BIM coordinator. In the BIM platform each individual building object or a building element could have several status values as shown in Table 5. The controlling information was collected using tablet once per week as the BIM coordinator walked through the site and changed and saved the statuses of building elements in the model. There were several days lag between the actual assembly of building elements and saving of the status information in the model, so the timeliness of the information flow and the visualization of the actual schedule was out of date.

The use of BIM software platform was practical enough to save the information quickly on site and foremen can learn to use the platform easily. Unfortunately in this particular case, the high quality and accuracy of information flow could not be reached.

3.4. Case 3: Information flow on precast concrete element production

In this project presented in Table 5, the same cloud-based BIM software platform as in the case two was used to manage and control the information flow between the main contractor and an ETO prefabricated concrete element provider. The ETO provider maintained and shared the production model that was based on the structural model for the main contractor. The production model was connected with the provider's ERP system. The structural designer transferred concrete element drawings from the designing software to ERP system automatically. The ETO provider, main contractor and the structural designer had an easy and efficient access to the information in the production model.

Table 6. The characteristics of the project in Case 4.

Type of the project	Two identical residential buildings, block of flats, Fig. 2 c)
Research subject	Information flow on precast concrete element production
Methods used	Visual Management
Site organization	One general foreman, three foremen and one site engineer
Digital environment	Personal mobile phones and laptops
The knowledge about BIM and Lean methods	Below the average level

For the controlling of the fabrication and supply situation to the site, the status tool was used in BIM software platform. Also, the statuses had the information where the prefabricated elements should be produced. The provider defined the statuses as they were used in the ERP system so the information flow in and out of ERP system to the elements in the production model was automated. The status values are presented in Table 7. The fabrication and supply situation was visualized practically, and the timeliness of the information flow could be reached.

Table 7. Status values used to visualize the production status and their interpretations in prefabricated element production.

Status value	Visualization	Interpretation
Enable	Light blue	The element data and drawing is imported to the ERP system
Commit	Dark blue	The element is programmed to be cast
Started	Orange	The element is cast
Paused	Red	Casting is prohibited
Completed	Green	Element has been delivered

Unfortunately, the high quality and accuracy of information could not be accomplished using the production model information. This was due to the missing information with prefabricated concrete element naming and identification numbering in the structural model. The naming and numbering of elements based on types of elements, and several same type of element had the same name and identification number. ERP system and the production model used by the provider could not itemize the elements with locations without Assembly Control Numbering (ACN).

Due to the fact above, the contractor had to order the elements batches using table formatted order form. When the batch arrived at the site, the contractor combined the information between the order and delivery forms and marked the delivery batch items on the layout drawings as delivered. Deliveries could not follow JIT principle, and a temporary prefabricated concrete element store was needed on site.

4. Results summary and discussion

The interviews pointed in the direction of traditional face-to-face communication, meetings and document-based information flow between project parties. Emails with attachments and phone calls are used to communicate with designers, subcontractors, ETO providers and material suppliers. On sites, limited access to the accurate and flawless design information and long response time to the request of information is an information flow issue according to the interviews and observations.

Step by step, digital information flow between parties and the knowledge to use desktops, tablets and mobile devices is changing the traditional site organization, roles, authority and power relationship on site. Observations showed that junior foremen can learn and takeover BIM software tools faster than senior foremen. There is no threshold to accept a new way of working with information flow if technology based obstacles are removed. The interviews revealed that the core of Lean philosophy was not fully understood, that is, no mentions of waste. Both the interviews and the cases identified several 'non value adding' functions — that is waste — during the information flow process. However, Lean tools like Last Planner System, Big Room, JIT principles were familiar with the interviewees and some of them were used successfully in the cases.

In the Table 8, the case results are summarized and presented. The proposed hypothesis of dependencies and interconnections with Lean construction methods, BIM and the characteristics of a good information flow can not been disproved by the results analysed by the researchers.

Table 8. Dependencies between methods and characteristics of good information flow in the cases.

		Cases	Easy and efficient access	High quality and accuracy	Timeliness	Reaching the right subject
Lean	Last Planner	1, 2	Improved	Partially improved	Improved	Improved
	JIT	3	---	---	No effect	No effect
	Visual Management	1, 2, 3	Partially improved	No effect	---	Partially improved
BIM	Design information availability on-site	1, 2, 3	Improved	Partially improved	---	Partially improved
	Quantity take-off and procurement	1, 3	Partially improved	No effect	---	---
	4D scheduling and actual progress control	1,	Improved	Improved	Improved	No effect
	BIM order and assembly visualization	2, 3	Partially improved	---	---	Improved

The interpretation of results shows that the use of Last Planner System, BIM-based design information, and 4D scheduling improve the information flow through easy and efficient access to information needed on site. High quality and accuracy of information in time scheduling could be improved using BIM method of 4D scheduling and actual progress controlling. The use of Last Planner and BIM-based design information improve the accuracy of information content and flow partially. The timeliness of information could be improved using Last Planner and 4D scheduling. The use of Last Planner and BIM order and assembly visualization could improve the flow of information to reach the right object.

At first, the researchers recommend the use of Last Planner and 4D scheduling in the project on site. Last Planner System is a visual and standardized tool for managing the information needed in work phase planning. Project parties share the information needed to reach the objectives of the project. 4D scheduling improves the timeliness and accuracy of the general and phase scheduling of activities and visualizes the content and the progress of construction works.

At second, the information gathered and needed in construction projects should be stored in digital format in a cloud-based system, which can be reached practically anywhere and with different devices, such as personal computers, laptops and mobile devices. The information should be stored in a machine-readable format. The information should also be as centralized as possible, in other words there should be as few different systems as possible to smooth the information flow within the site organization and between the project parties.

At third, every site should have a responsible person for collecting status information, updating the 4D schedule and doing other BIM-related tasks. This person should belong to the site organization and be located at the site to ensure the timeliness of the information.

At last, the researchers recommend implementing the Lean philosophy core of waste and continuous improvement in the project culture. Pilot projects should be arranged to test the use of lean principles, such as JIT deliveries. That could be used as an example of the method and its effect. By this existing example within the organization, site supervisors and project managers could be encouraged to utilize these methods in the future projects.

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