COMBINING BIM AND LEAN METHODS FOR COMMUNICATING DEMOLITION PROCESSES IN AN EARLY PROJECT STAGE

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Abstract

Demolition projects today face numerous challenges, including health and safety regulations, environmental impacts, tight construction schedules, and the involvement of multiple stakeholders with different backgrounds. Additionally, there is a significant amount of project data available in various formats. This paper proposes a method to address these challenges by combining Building Information Modeling (BIM) data, other project data, and Lean scheduling to visualize and simulate the project early on, before the general contractor is selected. This approach requires minimal additional effort from the client. By implementing this method in a large industrial demolition project, the paper outlines the process of combining BIM and Lean scheduling data. The benefits of enhanced communication and reduced complexity through visualization and simulation are discussed, along with the requirements for implementing this combined approach. The results demonstrate that a digital model integrating all relevant data fosters a common understanding among stakeholders and enables efficient communication, faster decision-making, and evaluation of the demolition schedule's consequences. This process is applicable when a BIM model and a Lean schedule are available to the project team.

Introduction

The demolition phase is the end of the lifecycle for a building and contains the complete elimination of all parts of a building at a specific location and time (Thomsen 2011, p. 327). Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of waste generated in the EU (European Commission, 2018). Construction and demolition waste „composes of solid, bulky, largely inert waste “(Asaari et. al, p.1) With the increasing population as well as more and more brownfield projects in urban areas the amount of waste will further grow. Besides this, also environmental, safety and security issues grow. With the regulation of the waste composition and tighter specifications in the treatment process there is a need for reducing the growing complexity in demolition projects (Tränkler 1996, p.21).

Few research with respect to demolition processes has been conducted so far. Research findings are often in the improvement of the material recycling. So most of the research topics are on product related topics, whereas in process related areas of demolition there is in general a lack of research. Besides this, the enormous amount of demolition waste shows a need for structured, transparent, and communicable demolition processes. Especially in urban demolition projects, there is a high complexity due to the required logistical planning: Laydown areas are limited and logistics needs to be well planned in advance. Here, BIM and Lean are applied in various construction projects around the world. Yet they have not been connected to use their full potential. The research aim is to identify the potential of combining a BIM model with a Lean schedule at an early stage (before general contractor nomination) regarding communication among all project stakeholders using a digital model. The methodology is a case study based in a real demolition project finished by a large industrial client in 2018. Including visual simulations using a BIM model and a lean construction schedule. The aim of this research paper is to identify a combined method of using Lean and BIM to use the full potential of both.

Demolition and deconstruction

Relevant terms in this article are "demolition" and "deconstruction" of brownfield projects. The term brownfield was originally used for commercial or industrial areas in the USA that are potentially contaminated with toxic waste or other pollution. The "brownfield project" is primarily an American term used in urban planning. Predominantly, after a demolition phase the construction phase or renovation phase of a building will start. In order to be referred to as brownfield, a certain pre-pollution or damage must be assumed. Projects in which an existing infrastructure or buildings are totally or partially demolished to carry out a new construction project are called brownfield projects. (Environmental Works 2015). CDW arises from those activities.

Demolition and deconstruction can be considered as a normal process of taking apart, compressing a building and disposing the waste. Deconstruction has a positive notion in comparison to demolition. There is a general distinction between partial demolition and total demolition. Partial demolition begins during the service life of buildings as part of the maintenance and the replacement of building parts, resulting in a considerable waste flow (Thomsen 2011, p.327). In theory this could continue until the whole building is replaced (one or more times) in a piecemeal manner (Thomsen 2011, P. 328). In contrast in a total demolition the whole building will be deconstructed, and more demolition waste will be generated.

Deconstruction has two phases: The first phase consists of the planning and scheduling of the deconstruction process. Here, a differentiated assortment of components and materials removed from the building need to be carefully sorted. Sorting is divided into the type of material, non-hazardous and hazardous waste. Waste materials can be categorized as follows: Concrete, bricks, steels, aluminums, woods and others (glass, electrical and plumbing fixtures, tiles etc.) (Asaari et. al p.2). In the second phase those deconstructed and sorted components and materials are reused or retreated in other buildings or transformed into new functions to avoid as much down cycling, energy transformation and deposit into landfill as possible (Thomsen 2011, P. 328). In the end, the demolition waste needs to be transported either to the landfill or to other sites for the reuse or retreatment.

Challenges in demolition and deconstruction projects

Demolition and deconstruction processes generally face big challenges as:

- Verification of the demolition schedule at an early stage to guarantee potentially tight time schedule.
- Complex sorting of material and components – waste needs to be sorted in a structured way and transferred into a material flow to handle the supply chain efficiently
- Complex logistical planning as differentiated assortment needs to be transported to the deposit or other sites while having a resource efficient planning of the supply chain.
- Environmental impact, safety and security issues of hazardous waste need to be regarded. Transparent and easy-to-understand communication to legal departments, government and construction companies is important to reduce waiting times in the demolition process.
- There are hidden characteristics of the existing structure. The client must be in possession of the complete inventory plans (Clade 2015, p. 175). When the demolition measures are carried out, further details about the existing substance are often revealed. To correctly adapt the demolition process and keep planned milestones, a fast decision-making by project managers and the ability of the trades to react rapidly is needed.

Takt planning

Takt planning is an often-applied method in construction projects based on the lean philosophy. The word takt derives from the latin word of “tactus” and means a steady beat. Hence, takt can be seen as a rhythm for a continuous production planning and control. A first well documented takted production system is found in a venetian shift wharf. Henry Ford introduced the method of takt planning and takt control to Fords assembly lines in 1913. Time and cost benefits were achieved by doing this. Later Womack and Jones described the method in their book “The machine that changed the world” in 1996 and further industries implemented it. In industrial production the product (object) is moving along work areas (subjects) with manual or automated stations in the defined speed. In contrast, in the construction industry the construction trades (subjects) are moving through the building with defined work areas (object) doing their work packages (Ballard und Howell 1998, Friedrich et al. 2013). The mechanism is transferable, only object and subject relation changes. Still, in both industries a takt has three dimensions: First there is the time dimension with the time interval between two beats which is called “takt time”. Secondly, there is the work area where the defined work is done. These are defined as “takt areas”. And lastly, there is the work which is done in the takt areas in the defined takt time. The work is the takt content. The three dimensions enable a transparent and structured process that can be easily communicated to all project stakeholders. The steady rhythm supports stability and a short-cycled quality control for a higher overall quality. Based on a stable process further quantitative benefits can be achieved. The takt time should be planned according to the client’s demand. According to Frandson et al. (2013) “takt-time is ‘the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate“. By reducing the takt time, construction trades are parallelized more and takt areas and/or the work packages need to be reduced. Resulting with this reduction higher potentials regarding project time can be achieved and single areas can be handed over quicker to the client.

Takt planning can be broken down according to the concept of Porsche Consulting to the following steps (KAMÜ Projektbau, 2016):

1. Identifying functional areas with the same process sequence.
2. Prioritizing areas according to the client’s demand and thereby also defining a proper construction direction.

3. Identifying a standard space unit (SSU) of each functional area which can be done as a stand-alone unit.
4. Defining a process sequence for each functional area and SSU.
5. Summarizing the quantities and the performance factors for each work package and SSU.
6. Identifying the bottleneck by a visualization of the workload (in a histogram).
7. Levelling the performance factors to a steady level by adapting labor resources, splitting and combing work packages (Körtgen 2010, S. 31). Defining takt areas by combining a multiple of the SSU according to the demand rate of the client (Frandson et al. 2015).
8. Creating a takt plan with the defined takt time, takt areas and the work packages.
9. Communication and possible adaptions of the production plan with all relevant stakeholders.
10. Defining frozen zones of the production plan in which process stability should be guaranteed by all involved stakeholders.

By breaking down the work of the total construction project in subsets production control is easier (Ballard und Tommelein 1999; Tsao et al. 2004, S. Grundlagen zu Lean Construction und takt 13 788–789). Required resources can also be decreased out of the production plan. Possible resources in a demolition project are required laydown areas for waste and recycled material, workforce, machines and tools for the demolition or needed information and plans.

Takt planning and takt control therefore respond to the challenges of demolition processes described above:

Easy communication to all stakeholders by breaking down the total demolition project in the dimension of time, area and work.

Ensuring tight time schedules and environmental impact plans by a forecasted and collaboratively planed production plan on a work package level

- Logistical feasibility study by adding required resources to the takt and verifying them per takt time and takt area
- Ensuring the adherence of safety and security issues due to a short-cycled production control.

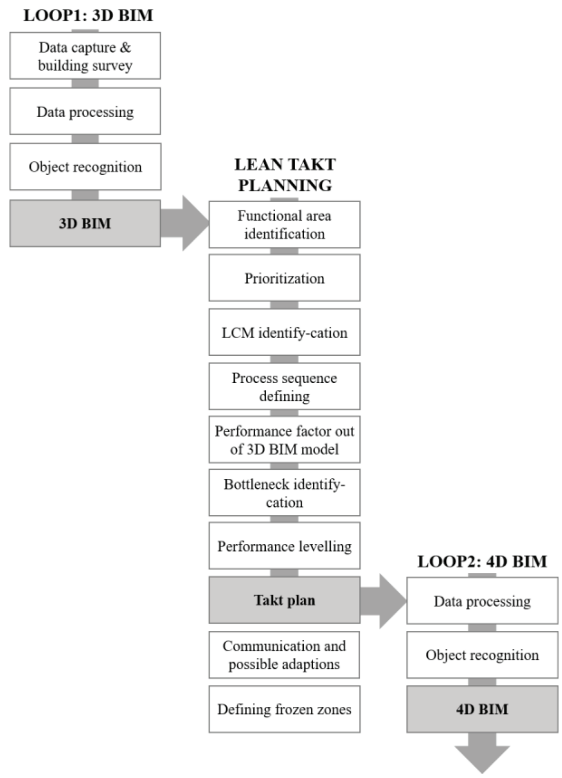

Figure 1: Combination of brownfield BIM and Lean process

BIM

Through the application of BIM (Building Information Modeling) within construction projects, a digital building model is created and used among project stakeholders. So far, this digital model is mainly used for design and construction purposes, although huge benefits are expected during the maintenance and demolition processes within the building lifecycle.

Following these potential benefits this work is focusing on verifying and communicating demolition processes and its implications among project stakeholders (Borrmann et al., 2015). The BIM technology provides reliable and accurate information to facilitate project management processes not only in construction, but also for deconstruction (Akbarnezhad et. al, 2014, Teichholz et al., 2011, Cheng et al., 2012). Especially the use for simulation purposes also referred to as 4D BIM (Boton, et al, 2015) is examined in order to show the benefits of using early simulation data to various project stakeholders with different professional backgrounds. Within the BIM world the difference could be made between brownfield and greenfield projects. In this case a brownfield application is inspected. Within a brownfield project there are often no existing BIM models to build on. In that case a so called "Points-to-BIM" process is applied. The reliability of the model is therefore strongly connected to the quality of data collection and its transformation to the model. Following Huber et al. (2011) the process consists of the following steps:

- Data capture & building survey
- Data processing
- Object recognition
- BIM Modeling

The result of these steps is an as-built BIM, which then can be used further.

The combination of the lean process and the brownfield BIM process (Huber et al., 2011) results in the process diagram in figure 1. Loop 1 results in a 3D

BIM model, by collecting existing site data. This model is further used to facilitate the lean takt planning by deriving area sizes and quantity takeoffs. The data from the derived takt plan is then returned into the BIM model, creating an additional dimension, a so called 4D BIM in Loop 2. Within the 4D BIM model the structural and quantity data is enriched with the takt time schedule linked to the structural and aerial attributes.

The Case Study

The presented methods and tools were applied on a 30,000 sqm demolition of an industrial building from the 1960s in the UK. The client is an international car manufacturer defining high standards for waste management, time schedule and demolition related impacts to the surroundings. The project is located within a mid-sized town and therefore there were special requirements regarding noise and dust. Throughout the existing building, there were different forms of contamination, the most important being asbestos in different applications, led based painting and oil-contaminated concrete. Therefore, the major challenges of the project were:

- Tight time schedule to clear space for further development
- Management of contaminated construction waste and its logistics controlled by external consultants
- Demolition process with minimal impact on surrounding areas
- Transparent communication to internal and external stakeholders

The project team consisted of the internal client and project manager, an external project management, several external environmental consultants, civil engineers, and architects as well as an internal and external health and safety auditing team.

To get the relevant data for the tendering documents, various site inspections were executed. Based on these available project data the decision was made to design an as-built BIM model containing the relevant structural and material data for the demolition process. The material data contained crucial information regarding hazardousness, amount, and contamination. Building on this data a takt planning workshop was held with the whole project team to align the processes with the defined requirements before tendering for a general contractor. The workshop resulted in a demolition takt plan (project schedule) including the requirements from environmental consultants for the treatment of hazardous and contaminated material. Further the location, time, and process data from the takt plan was incorporated into the BIM model. This BIM/Lean combination was designed in a flexible way. Therefore, the project management could change the takt plan and the BIM simulation was automatically updated. The insights from this project were incorporated into the tender documents, therefore all offers where using roughly the same takt areas. This offered great transparency for comparing the different bids.

Simulation

The simulation presented in this paper consists of three major data inputs:

- As-built BIM established through site surveys
- A demolition process developed within the project team
- A project schedule based on the takt planning method

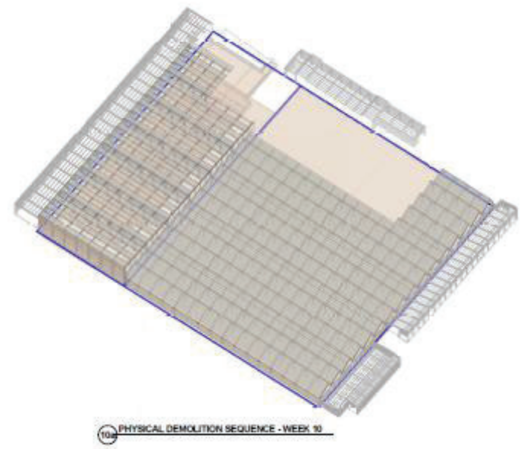

Figure 3: Structural model of building (3D BIM)

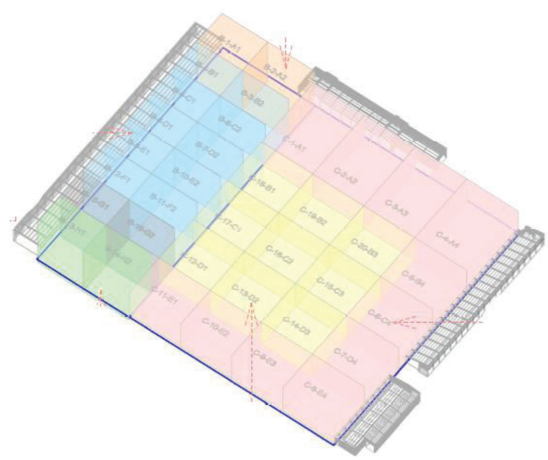

Figure 2: Defined functional areas in building structure

Within this chapter the tools and data inputs used in the process and their interaction are described. The 3D model of the structure was designed in AutoDesk Revit, the data for the building structure was gathered from old paper-based drawings and various visual field surveys. Additionally, the model was enriched with contamination information of the different building

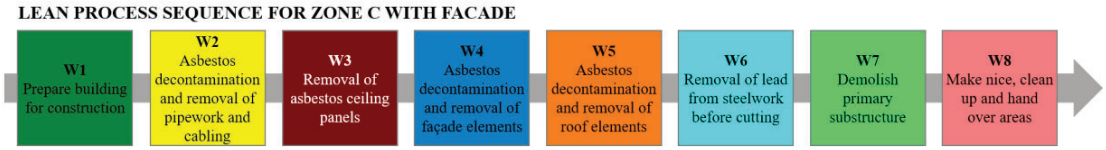

Figure 4: Example of a process sequence zone C

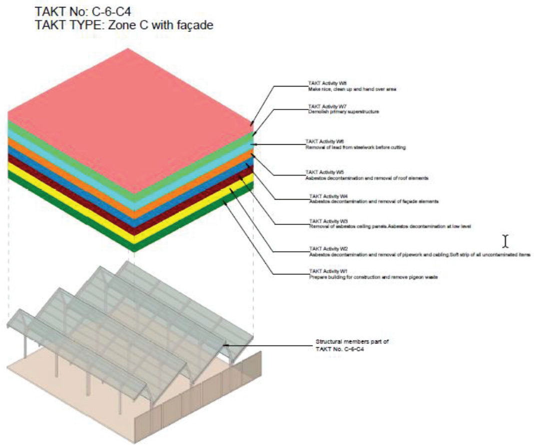

Figure 5: Schematic process visualization of zone C with facade

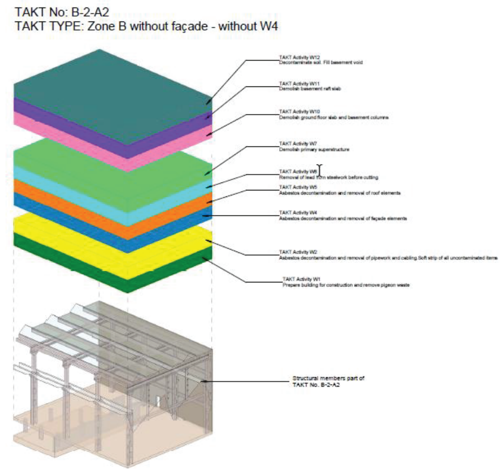

Figure 6: Schematic process visualization of zone B without facade

parts. The generated BIM model (figure 2) was the basis for the process design and scheduling workshop. According to the takt planning method all project stakeholders, with their distinct field of profession, took part in a one-day workshop. The result was different demolition processes for different functional areas (zone B and C, see figure 3) of the building, depending on the waste handling requirements, structural dependencies, and environmental impact of the demolition. During the workshop the BIM model was used to visualize the different areas as well as the structure of the building. Based on those structural requirements for ensuring a safe demolition, the process was designed following a Last Planner like approach using post-it notes (Seppänen et al., 2010). Following up the workshop a BIM process model for the different functional areas was designed in Revit. Compare figure 5 and 6 as examples for the color-coded process visualization and its linkage to the structural model. The process order in the BIM model is bottom-up, incorporating the result of the process analysis (figure 4). The sequence of trades through the building is visualized in figure 3. For the later linkage to the data model each takt area in the building got a code, this code was then translated into a color-code.

Each color defines a process step in a standard space unit (SSU) of the building. Combing the structural information with the different steps allows the derivation of waste flow and needed resources.

This combination of structural and color-coded process visualization enables an easy communication within the project and the impact of decisions made regarding the process. Hereby the differences in the structure and processes from zone B and C can easily be recognized (compare figure 5 and 6).

After the processes were designed, they were used as a basis for the time schedule of the project. Therefore, the method of takt planning was applied. Using the experience from the project team, resources and time for the single process steps were defined. Based on the duration of processes the single steps were leveled following a takt time of one week. This led in zone C with façade to a process with eight leveled work packages (figure 4) defined as process wagons [W1,…, W8]. All scheduling data was visualized in an Excel based takt plan (figure 7). The takt plan is build up on three dimensions. The x-axis is showing the takt time, which in this instance is on a weekly basis, the y-axis shows the different takt areas, the quadrant between the axis is containing the takt with the linked process wagons.

All described data inputs are combined with the tool Dynamo (http://dynamo.org) to connect the different data sources and let them interact with each other. The simulation was developed under the need for flexibility regarding data changes. Therefore, it is possible to adjust either structural, process or schedule data without programming skills. This allows for the simulation and visualization of different options for the demolition process. This model flexibility allowed for the simulation of different demolition scenarios before General contractor nomination and therefore the tender documents could be enriched with detailed process data to get the client's expectations right the

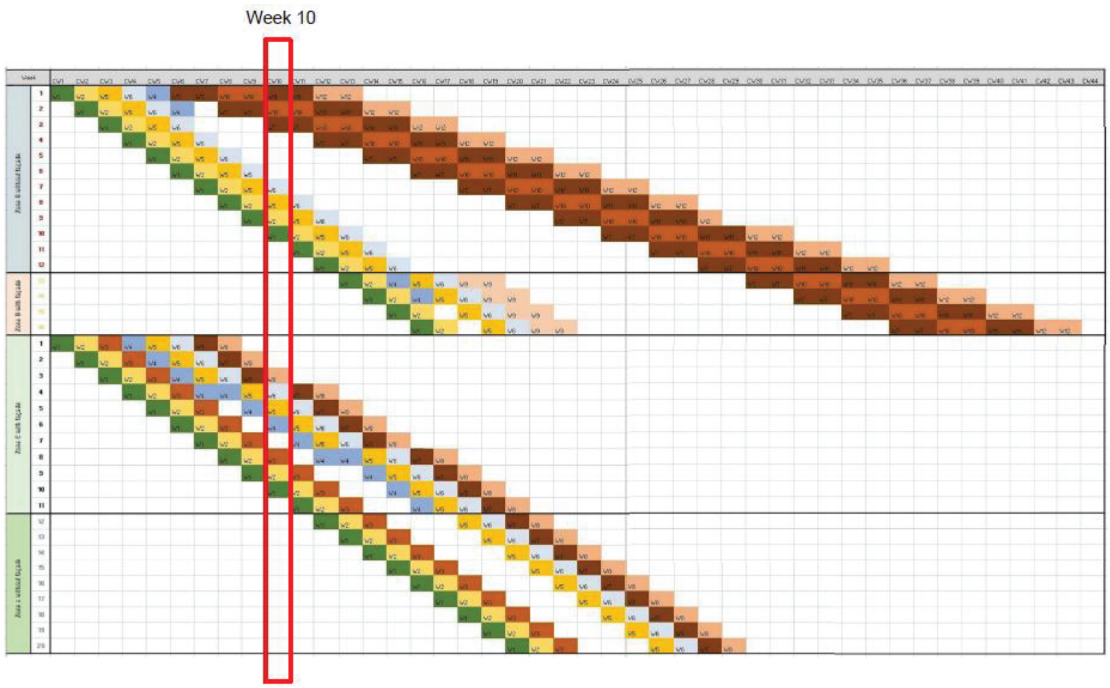

Figure 7: Excel based takt plan showing different functional areas and weeks

first time.

Conclusion and Discussion

Within the project the application of a combination of BIM and Lean methods was shown. Additionally, the benefits in regard to the transparency of schedule, waste management and communication of demolition processes and their impacts to the environmental, safety and security requirements were discussed with the following results:

- The demolition schedule was verified in an early stage in a collaborative planning workshop with all project stakeholders. This ensured the client's requirements of a tight time schedule to free the area. The various types of contamination were visualized and therefore the complex sorting of demolition waste could be planned upfront for the different building areas. This allowed for a managed logistics stream by pre-calculating the expected volumes of waste.
- Before going out to tender for a general contractor the direction of the process was defined considering the requirements of the neighbors, who expected as little as possible noise and dust disturbances (See figure 3, demolition from yellow to red areas)
- Additionally, the here presented combination of BIM and Lean offers a great flexibility regarding hidden characteristics of demolition projects. The takt schedule and logistics streams could be changed on the go and visualized within the model.

Further research and investigations are needed to verify the presented process for greenfield projects. Still the combination of BIM and Lean offers great benefits to verify and communicate processes. Furthermore, the presented process and the used tools are not limited to the presented use case. The used process was setup with a certain flexibility in mind and therefore for adaption for future projects. Using this structured way of data representation offers the possibility of agile data-driven process design and decision-making in construction projects.

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