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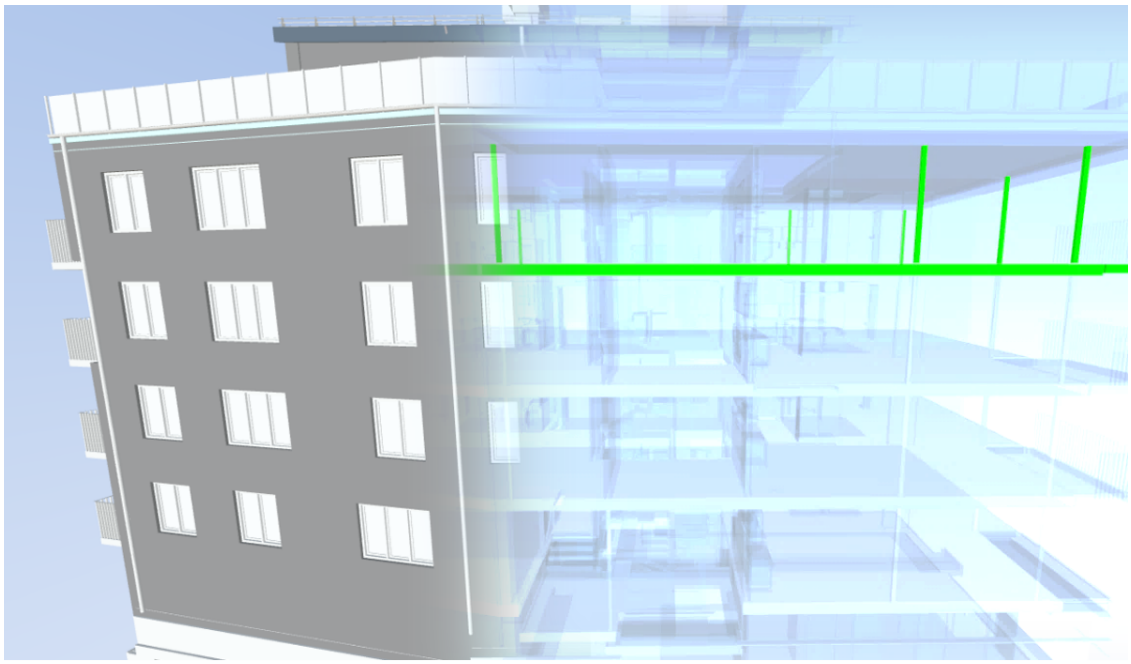

# Enabling a Broader Use of Time-Coupled Building Information Modeling

## Understanding current barriers and investigating takt planning as a catalyst for implementation

Master's thesis in Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
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# Abstract

Time-coupled Building Information Modeling (BIM) is a powerful tool for integrating BIM and production planning. This paper reviews the literature and interviews conducted with practitioners in the construction industry to test the benefits mentioned in the literature. The interviews showed that StreamBIM has the potential to integrate BIM into existing workflows and tools. It also enables the development of automated methods for this integration. In addition, the interviews show that BIM's flexibility and ability to visualize 3D for production planning can be improved by combining BIM with a takt-time plan. The results from the interviews suggest that iterative and continuous usage of time-coupled BIM needs to be done to make on-boarding easier for both clients, designers, and contractors.

Keywords: BIM, 4D, StreamBIM, Takt planning, Scheduling with BIM, time-coupled BIM.

# Acknowledgements

This master's thesis marks the completion of five years of studies in Civil Engineering at Chalmers University of Technology during the fall of 2024. The process has been both challenging and rewarding, and we owe its success to the support and input of many individuals and organizations.

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Finally, we want to thank our friends and families for their patience and support during this journey. Your encouragement has helped us stay motivated through every stage of this process.

This thesis is the result of many contributions, and we hope it provides valuable insights and adds to the ongoing development of the construction industry.

Axel Hjelmqvist & Ronja Sandros - Gothenburg, 12025

# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|---|---|
| BIM | Building Information Modeling |
| 4D | time data added to 3 dimensional geometry |
| IR | Information Requirements |
| OIR | Organizational Informaton Requirements |
| AIR | Asset Information Requirements |
| PIR | Project Information Requirements |
| EIR | Exchange Information Requirements |
| IDM | Information Delivery Manual |
| IDS | Information Delivery Specification |
| LCM | Lowest Common Multiple |
| LBS | Location Breakdown Structure |
| SSU | Standard Space Units |
| WDM | Work Density Method |
| AEC | Architecture Engineering Construction |
| AI | Artificial Intelligence, Machine Learning and Large Language Models |
| LOD | Level Of Detail |
| MPDT | Model Production Delivery Table |
| IFC | Industry Foundation Classes, a file format to describe building information |
| MMI | Model Maturity Index |

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# 1

# Introduction

With Building Information Modeling, BIM, becoming more adopted in the industry, interest in information coupled to 3D models has increased and one area which is seeing more interest but little usage is 4D (Boton et al., 2023). 3D models with a time-specific component creates a 4D model (Mahalingam et al., 2010). In the context of civil engineering, 4D allows planners to view a 3D model at the expected time of construction and only see relevant and realistic surrounding data and models to that time stamp (Russell et al., 2009). 4D models can be used in construction projects during several phases as visual support for different stakeholders and to enhance collaboration (Boton et al., 2013). According to Boton et al. (2023), risk management and construction progress overview are two areas that benefit from the support of 4D. Therefore, 4D is a way to enhance the construction of a project. Planning the construction of a project is critical to ensure that the construction itself is carried out logically and efficiently (Butkovic & Oloke, 2019). The planning is usually done by the construction planner who has good understanding of relationship logic between activities and can break down these activities into smaller tasks. A method for planning is takt planning which establishes a rhythm and a flow for the production to follow that aims for an efficient construction process (Joonas Lehtovaara, 2024). Takt divides the work required into more managabe parts by dividing the worksite into equally sized zones. The set of tasks that a trade performs in a zone during one takt time can also be reffered to as work packages (Joonas Lehtovaara, 2024).

A takt time plan can be coupled with BIM, which together can create a 4D plan for a construction project (Steuer et al., 2023). Furthermore, Steuer et al. (2023) describes how connecting the takt time with the BIM provides three points of views. The first one is the time dimension, the second one has a focus on the work area, and the last one focuses on the work being done in an area at a specific time. The dimensions in a takt time plan facilitate a structured process which is easily communicated to different stakeholders of a project. Takt planning has the benefits of increasing the predictability of the work, create a transparency for activities and provide an early detection system, and creates a strong collaboration between actors (Joonas Lehtovaara, 2024). The takt time plan can be coupled back to the BIM model to create a time-coupled BIM that allows quantitative data to be linked to scheduled activities, which further enhances the planning of the project (Steuer et

al., 2023).

Clarification for the difference between 4D and time-coupled BIM: When a time plan and a BIM model are connected it will be refereed to as time-coupled BIM. 4D will be used only when time is linked to a basic 3D model without information.

Time-coupled BIM has been established to provide a construction project with many benefits but practicioners are still hesitant or reluctant to commit to the methodology of BIM related planning (Martins et al., 2022). Martins et al. continues that lack of onboarding stakeholders, software interoperability, and high investment cost are seen as barriers for implementing BIM which is also applicable for implementing time-coupled BIM.

Because the construction projects that have implemented time-coupled BIM is deemed to be pioneers in the field, like in the United States, the attitude towards the result of time-coupled BIM is often viewed in a positive light (Martins et al., 2022). Therefore, the effect of implementing time-coupled BIM would be of academic interest in an environment where barriers such as lack of onboarding stakeholders, poor software interoperability, and high investment cost still exists. Furthermore, exploring the outcomes of implementing time-coupled BIM for a project that lacks economic incentives and knowledge of time-coupled BIM could gain valuable experience for both practitioners and academics in utilizing the strongly theoretical benefits of time-coupled BIM. Additionally, it is of academic interest to investigate whether time-coupled BIM would naturally become integrated into planning if the previous mentioned barriers were removed.

## 1.1 Aim

The aim of the thesis is to evaluate how time-coupled BIM affects communication and coordination among project stakeholders by using takt planning combined with BIM. Furthermore, a takt time plan will be developed in a BIM based and datacentric collaboration platform and used as a part of the data for the evaluation. The aim is to study the potential effects of digital tools, such as StreamBIM, and how they might impact construction project management. By doing so, the goal is to contribute to the understanding of making project execution more efficient and streamlined. By examining today's practices and settings, the study aims to understand the current challenges and opportunities with digital tools and time planning methods.

### 1.1.1 Research Question

With the previous information as background, the research questions are thus:

1. What is the maturity for implementing time-coupled BIM in Sweden?

2. How widespread is the usage of takt planning in Sweden?

3. Can takt planning be an enabler for time-coupled BIM?

4. What are the effects of implementing time-coupled BIM in a construction project?

## 1.2 Limitations

The master thesis was conducted within the limited time frame from September 2024 to December 2024, which may constrain the depth of analysis. The empirical data collection focus on takt planning and BIM, and is centered primarily within the Nordic countries, with an emphasis on Sweden, while the literature review draw from international sources to broaden contextual understanding. Interview participants were selected based on expertise in time planning and BIM, without restrictions on specific roles, companies, or geographic areas within the Nordic countries. This in order to capture a comprehensive perspective. However, this approach may limit detailed insights into challenges or methods specific to certain regions or companies.

# 2

# Literature Review

The following chapter contains a literature review which consist of an in-dept look into BIM, time-coupled BIM and takt planning. By examining these topics, the chapter aims to provide a solid theoretical foundation for understanding how these tools and methodologies influence project planning, coordination, and execution in the context of modern construction management.

## 2.1 Building Information Modeling

In order to grasp the concept of time-coupled BIM it is crucial to understand the concept of BIM and the need of structured information requirements to ensure sufficient information delivery.

The usage of Building Information Modeling, BIM, has long been claimed to help the construction industry in handling production problems (Gledson & Greenwood, 2016). Furthermore, Gledson and Greenwood (2016) state that the main benefit of using BIM has been argued to be to provide more information for decision makers faster. Instead of having to measure, predict or calculate information at the required time, it can be pre-defined in the planning of the project and then be available during the production phase to all relevant stakeholders at the time of need.

The information for the modeling comes from all involved disciplines which gives users of BIM all required information for the whole project and its construction process (Ljung et al., 2023).

However, BIM models suffer from low interoperability and badly designed information requirements (de Marco et al., 2024). This leads to poor information quality and complicates information transfer with multiple formats and file types which in turn requires cumbersome manual information transfer. Furthermore, when in the construction phase, workers find it difficult to extract the information that they need from the BIM which leads to design teams putting extra resources to present 3D or 2D views with annotations (Disney et al., 2022). Disney et al. also explain that visual management coordination tools such as BIM 360, StreamBIM and Naviswork have proved to enable construction workers to utilize the BIM model for their needs.

However, this requires the BIM to be correct and the information to be extensive enough to cover the needs in production.

### 2.1.1 Information Delivery

A reoccurring issue with BIM in general is the lack of defined information requirements which leads to low interoperability of information between deliverables (de Marco et al., 2024). The poorly defined information requirements results in the need for time-consuming manual processes where information is added after all deliverables are connected.

To provide guidance for defining information needs, the ISO 19650 Parts 1, 2, and 3 are used to help establishing main requirements based on Organizational Information Requirements (OIR), Asset Information Requirements (AIR) and Project Information Requirements (PIR) (Kemp, 2021). OIR relates to internal operation for a project which helps the organisation efficiently work with the project and ensure a good delivery, an example of an OIR could be a policy to confirm all necessary statutory approval before project start. AIR outline the information necessary for operators to manage assets through their life cycle. The requirements are designed to support for instance maintenance and performance monitoring. AIR should be defined by the asset owner before any project appointments to ensure all stakeholders understand the data expectations. This preparation stage is essential to avoid unnecessary information exchange and ensure that the BIM data supports asset operations effectively. Kemp (2021) further explains that PIR specify the information needed to support decision-making at key project stages. Defined by the project client or asset owner, PIR can include requirements such as KPIs, financial details from the project business case, strategic programs like opening dates for a business, and information needed by project stakeholders. With the AIR and PIR established, the information to be delivered can be more precisely defined in the Exchange Information Requirements (EIR).

EIRs are crucial components in ensuring that the information produced by the project team aligns with the needs of the client and other stakeholders. This approach is intended to ensure that only the information critical for decision-making or operational activities is provided, improving efficiency and interoperability across teams. Dr Anne Kemp OBE (2020) emphasizes that EIR must be meticulously defined and managed to avoid unnecessary information.

Another proposal for creating correct BIM models have been to follow the Information Delivery Manual (IDM) (Jeff Wix, 2007). The IDM helps in creating the common understanding of information that is needed for the creation of BIM. It includes specifics about which stakeholders are affected by and in need of what information, what information should be created, and how software can support with providing the wanted information (Jeff Wix, 2007). Furthermore, the IDM aims to standardize the BIM process (Jung et al., 2024). As explained by Tomczak et al. (2022), IDM is more centered around 'by who' when it comes to information requirements (IRs).

What tool to use often depends on the project-specific needs which highlights that there are not one-size-fits-all solution for information delivery (de Marco et al., 2024). A standard that has seen more recent use is an Information Delivery Specification (IDS), which sets up a framework that specifies the exchanging IRs. An IDS is set up to be imported to a software of use, read and understood, used as a framework for assigning information for a model, and then used in the validation of information assignment. It is used in the context of IDS controls (de Marco et al., 2024). What the IDS should check can range from property, predefined types, classification, material or entity (Tomczak et al., 2022). It is most commonly metadata that is coupled to a 3D element.

It is important that the information delivery is correct since the BIM serves as a basis for the planning phase of a project (Tomczak et al., 2022). With a more complex project or model, the level of detail has to become higher for the IDS. This is to ensure that the decisions surrounding the project, such as creating a construction plan, are done on qualitative information. The BIM can thereafter serve as the foundation for the planning process (Zhang et al., 2022).

## 2.2 Takt planning

One way to plan the construction of a project is to implement a takt time plan. Takt planning or takt time planning derives from the German word 'Takt' which refers to 'rythm' or 'cadence' with which something gets done (Haghsheno et al., 2016). Furthermore, a takt time plan is constructed of predetermined repetitions of processes with the same duration. Between two beats of a takt, there is takt time and according to Frandson et al. (2013) takt time is the time needed to produce a product in order for the supply to match the demand.

Takt planning is not a new concept and has been used in different industries since the 16th century (Haghsheno et al., 2016). Takt time for construction of buildings was first recorded during the construction of the Empire State Building in New York in 1930 and today takt planning is used in construction processes which have frequently repeated procedures, such as residential buildings. This is, according to Haghsheno et al. (2016), since when the content of a takt is planned, it can be repeated continuously. As all levels aren't designed identically when constructing a building, an early takt time plan should show how work in different construction

phases connects to create a smooth overall process (Riekki et al., 2024). It should identify unique areas that don't fit well with other phases and include them in the plan and workable backlog areas can be utilized to balance low-density work in some parts of the project.

### 2.2.1 The construction of a takt time plan

A takt time plan is combined by four elements set out on a single poster where the connections between the elements can be clearly visualised (Holm et al., 2018). These elements are zone, train, wagon and takt.

When using a takt time plan, a project is divided into small time segments and spatial areas where the work is determined and structured. The spatial areas are designated areas in the project where trades will be coordinated and managed. They will be referred to as zones but other common terms are takt areas, work areas and control areas. A project's ideal zones include work that have the same duration for each trade (Frandson et al., 2013).

What usually is called a process, is in this context called a train (Holm et al., 2018). It is the sequence of activities which are needed to complete the work in a zone. The set of tasks that a trade performs in a zone during one takt time can also be reffered to as work packages (Joonas Lehtovaara, 2024). These activities are then described in depth trade by trade as wagons (Holm et al., 2018).

A wagon is an activity in a train. Each wagon consists of a set of tasks and preferably a wagon consist of one trade but depending on the complexity there could be multiple trades in a wagon. However, there is only one trade who is responsible for the wagon.

A takt is the duration of a wagon. To achieve the best possible rhythm and production flow, the workflow need to be planned in detail.

Frandson et al. (2013) has identified six phases for producing a takt time plan which are concluded in Table 2.1.

**Table 2.1:** Takt time planning steps

| | |
|---|---|
| Step 1 | Gather information |
| Step 2 | Defining zones |
| Step 3 | Understand and determine the trade sequence |
| Step 4 | Understand and determine the work content per zone |
| Step 5 | Balance the workflow |
| Step 6 | Develop the production plan |

According to Melzner (2019), the steps involved in producing a takt time plan should be reviewed to identify the requirements for exchange related to process planning. This can be accomplished by addressing the following questions:

- Who is requesting?
- Why is the information important?
- When is the information needed?
- What information supports the request?
- To Whom is the information intended?

#### 2.2.1.1 Gather Information

In step 1, the goal is to identify what work is to be done where (Frandson, 2019). This can be done by having foremen highlight what work they can do in for example a week. This results in 'color-ups' which are exemplified in Figure 2.1. During the color-ups, each trade uses a different color to mark their work are on the floor plans. Frandson (2019) continues that color-ups require thought on how, by whom, where and in what sequence the work will be performed in difference to quantity take-offs which are more general and focus on amount, in order to support estimating and procurement. One way for planners to gather the information from the trades is to ask questions that identifies each trades preferred duration and individual production plan. However, Frandson mention that it is quite unlikely that individual trades get to work as they showed during the color-up.

Figure 2.1 shows an example of a color-up where the zones are divided into one week's work.

#### 2.2.1.2 Defining Zones

Zones are preferably the lowest common multiple (LCM) for repeatable elements. This since projects with multiple repetitions on related construction stages are well-suited for takt time planning (Melzner, 2019). The first step in developing a takt time plan is to define these zones. If a traditional process planning method is being used, steps 1-4, including determining the trade sequence, work content and labor effort per work content per zone, involve extensive effort since all information must be gathered from different documents such as tender specifications and expert reports. When a project uses BIM-based process planning, the information needed for steps 1-4 can be gathered directly from the BIM-model.

According to Tommelein and Emdanat (2022), zones can be determined through four different approaches. These approaches differ in what objectives are pursued, how changes are made when optimizing the plan as well as what information they assume is given at the start of the planning process.

An approach is to start by defining a Location Breakdown Structure (LBS) for either a phase or the entire project and then assess the work in each location and choose means and methods while sizing the trades crews (Tommelein & Emdanat, 2022).

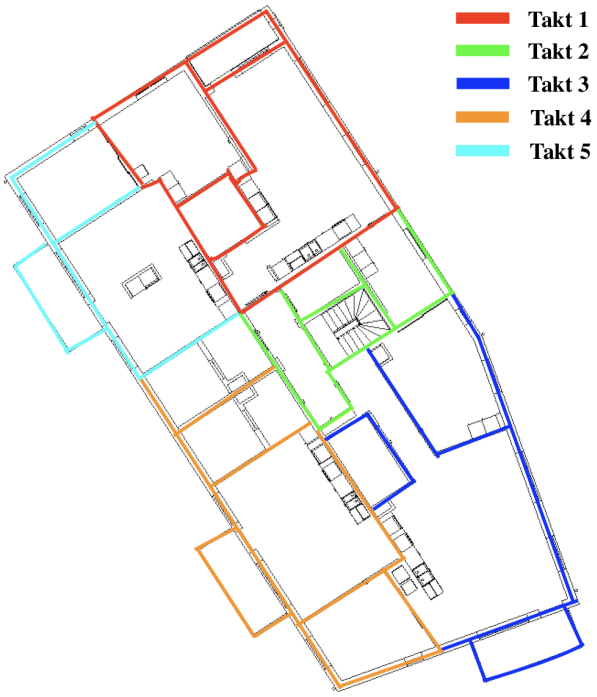



**Figure 2.1:** Example of a Color-up of 5 takt zones on top of a floor plan

This approach is mostly used when having location-based methods and the objectives are to keep the trade crews size constant, bypass crew overlaps where multiple trades work in the same location, and have the trades crews work in sequence. This in order to have high resource utilization and buffering with time.

A second approach is to first identify Standard Space Units (SSU), such as a hotel room, bathroom, or office. Then, the work content for each trade is determined, followed by multiplying this with production rates to calculate the time each trade requires per SSU. Finally, resources are adjusted to establish an acceptable upper limit on the duration allowed for each trade to complete their work in each SSU.

Further, Tommelein and Emdanat (2022) states that the third approach can be labeled "block planning" and starts by choosing the duration between handoffs. This time is called a takt wagon. Following that, the site can be divided into zones to create time-space blocks. When the blocks are created, one can decide what tasks can be done by which trade in each zone during the selected time frame. This could possibly result in numerous trades ending up in the same wagon.

The fourth approach uses Work Density Method (WDM) which is based on identifying what work steps trades must execute in a process and mapping the needed time for each crew in a fine grid of cells. This grid is then placed over the work space. The identification can also be done by color-ups. For example, the amount of work the minimum crew can do during one day can be identified by a single-day color-up. The cells are then combined to divide the work space into zones. The zones

can be optimized to crew capabilities, means and methods by using mathematical optimization to find the lowest workload possible.

#### 2.2.1.3 Balance the Workflow and Sequence of Activities

When moving on to step 5, Determining content and time of the takt and adjusting capacities, Melzner (2019) continues that a review of the previously calculated workload needs to be adjusted to the takt time. During this step, various parameters are taken into consideration. Among others, adjusting the number of employees and shifting services within a work train. A work train can be defined as the natural sequence of activities which are needed to complete a zone and are described trade by trade (Holm et al., 2018). What parameters being considered differentiate depending on the approach used for zoning. Furthermore, work packages can be compiled in the same wagon if there are no collision and no mutual influence is expected.

To be able to balance the workflow, understanding of trade sequence is required which is easiest done by coordination meetings (Frandson et al., 2013). In this step, trade activities that need to slow down or need to go faster are being defined. There is also a possibility to adjust the zones to balance out the workflow.

In the first resulting step, step 6, wagons and trains are being formed (Melzner, 2019). Here, one can change the construction strategy and thus change the construction process. An example is that the direction of the workflow as well as number of trains can be varied.

### 2.2.2 Benefits for production

Takt planning breaks down processes into manageable, regularly timed segments, ensuring that deliverables are provided consistently. There is great focus on the planning stage, which has great potential to boost revenues, quality and increase productivity as you are more thorough in the planning stage (Holm et al., 2018).

According to Tommelein and Emdanat (2022), takt analysis in previous projects has improved the understanding of requirements for new system installations, enabling an assessment of potential design adjustments needed to meet those requirements. In the same projects, several bottlenecks were identified with the analysis before the work had started, enabling the team to solve the issues early.

Eetu Heiska (2024) explains how regular site meetings discussing the progress ensures that information flows seamlessly and everyone knows their tasks. He also explains that one of the greatest benefits of takt production is that it reveals what delays the project which gives the opportunity for continuous learning. As the takt time plan can be updated during the production, these issues can be addressed and resolved quickly which increases the productivity considerably.

## 2.3 Time-coupled BIM

3D BIM coupled to time adds a fourth dimension to create time-coupled BIM (Gledson & Greenwood, 2016). This allows for the BIM to simulate the construction over time which is a more accurate representation of progress during construction and planning than a static 3D model (Boton et al., 2023). The construction process is better visualised through time-coupled BIM than a complete representation of the building using 3D BIM. There are several key benefits to implementing time-coupled BIM and practitioners deem it to have high potential (Boton et al., 2023).

Boton et al. (2023) states the following as benefits of time-coupled BIM:

- Visual construction scheduling
- Analyze construction issues
- Spatial and time related collisions
- Concept communication
- Construction logistic simulations

Furthermore, according to Steuer et al. (2023) a digital model that integrates a complete set of data that is relevant to the project, unlocks opportunities for more efficient communication and provides a medium for a common understanding for all stakeholders. This is reinforced by how time-coupled BIM has shown to simplify the communication between team members through a visual representation (Martins et al., 2022). The usage of time-coupled BIM to create early simulations for various project stakeholders have also shown to mitigate and anticipate problems for the construction before any progress in production have been made (Boton et al., 2015). Furthermore, time-coupled BIM can be used to solve issues that arises during construction by testing multiple solutions and deciding on the most optimal. Visualising a time and spacial relationship between BIM and a schedule improves the planning techniques of construction (Gledson & Greenwood, 2016). Moreover, it can help in assessing the implementation of construction schedules and minimize oversights or faults in the schedule while also improving communications for stakeholders of the project (Gledson & Greenwood, 2016).

Time-coupled BIM also enables the ability to plan and assess temporary installations with the temporal building information, which allows for better decisions throughout the project (Martins et al., 2022). The productivity of a construction site can be negatively impacted with a 65% decrease due to congestion of the site (Zhang et al., 2022). Zhang et al.(2022) defines productivity as work hours per area unit where less hours per area of building built is viewed as more productive. The spatio-temporal analysis from time-coupled BIM can help construction practitioners with detecting conflicts or logistic simulation before anything is built or make detection's during

construction if there are any introductions of change to the schedule (Boton et al., 2023). The benefits of using time-coupled BIM simulation for a project and the industry as a whole, is estimated to be 40% more productive overall compared to traditional planning methods when measuring work hours per area unit built (Zhang et al., 2022).

The usage around the world of time-coupled BIM varies and there are some countries that stand out like the United Kingdom, Australia and United States of America (Martins et al., 2022). The US sees big push for BIM in the private sector while the UK experience mainly commitment from the government. For Australia, a collaborative approach was created through the buldingSMART foundation that invited stakeholders from the AEC sector to workshops and introduced easy-to-use methods that laid the foundation for the integration of BIM (Martins et al., 2022). In Sweden, Introduction of BIM in the private sector can be done by applying the Total BIM as a key company strategy and support it by hire employees with digital competences (Disney et al., 2022). Total BIM aims to use the projects BIM for everything and essentially become drawing-less. In Norway the use of BIM is very common but the use of time-coupled BIM are rare in projects over 20 million NOK (Hosamo et al., 2024). In the study conducted by Hosamo et al. (2024), it was explained that the cost and perceived utility are factors that limits usage of time-coupled BIM. The study also mentions that smaller projects are easier to manage manually and does not require time-coupled BIM to complete.

### 2.3.1 Information Delivery for time-coupled BIM

As previously established, BIM delivery consists of information coupled to a model (Martins et al., 2022). Deliverables interoperability becomes particularly complex with the addition of time-coupled BIM (Boton et al., 2015). This is because the schedules that the time component consists of is additional information that needs to be incorporated, the requirements and standards that applies to other part of the BIM needs to also be integrated to schedule practitioners workflow.

To manage these issues, IDS can be a way of creating clear requirements for BIM deliverables by validating the BIM towards the specification (de Marco et al., 2024). Evaluations of incorporating IDS checks into practitioners software before delivery, have proved that IDS leads to increased model quality and validation efficiency. The limited use for IDS have mainly been due to lack of awareness and adoption outside of pioneering firms and academia (de Marco et al., 2024). To further realize the benefits in BIM interoperability, IDS needs to be seamlessly integrated into existing workflows. de Marco et al. (2024) explains that plug-ins or ad-ons for the current practitioners software, is a means of effective integration.

### 2.3.2 Time-coupled BIM with takt planning

When takt planning is coupled with a model, it creates time-coupled BIM. As mentioned in subsection 2.2.1 Melzner (2019) states that there is a big difference in the workload of takt planning already in the early stages of the planning phase if a BIM-based process planning is being used instead of a traditional method. Melzner further states that the effects of changing the construction process can be analysed directly in a time-coupled model which can guarantee optimal use of resources.

The input data for the schedule generation can be generated from the BIM (Melzner, 2019). Since the building structure is hierarchical with each element containing GUID, type, Material, Section, Coordinates, and so on, the building elements informs the process planning.

A study by Kim et al.(2018) proposed a framework and algorithms that helped combining planning and BIM, creating a time-coupled BIM simulation, to plan for temporary structure installations. Connecting BIM and schedule activities can be done by pairing processes to user-defined zones of each floor (Zhang et al., 2022). The zones contain elements which creates processes depending on element type. Combining BIM and Artificial Intelligence (AI) is deemed to be a way of further automating the process. A recent study by Jung et al.(2024) of using AI, which in this case means large language models, shows an approach to lower the amount of manual work that is required for BIM-data management. This method uses logical way of reading information from one list, i.e. properties of a 3D model, and comparing it to a list of scheduled activities. It uses a set of rules for the comparison that is predefined, a database that consists of data from past projects to enhance the match, and produces a quality indicator of the match between activity and model. According to Jung et al.(2024) this allows for automatically creation of time-coupled BIM. The automatic tests explained by Jung et al.(2024) showed a promising f1 score which is a score of predictive performance 0-1 where a score above 0.9 is considered as excellent. The score for the tests were 0.87 in one category and 0.93 for information classification according to the standardized Uniformat Level 2 and Level 3 respectively (Jung et al., 2024).

### 2.3.3 Implementation difficulties

There are few studies were the information of the BIM is structured to accommodate takt planning (Ljung et al., 2023). Projects that have used BIM are found to be impacted negatively by software and hardware limitations which may discurage future usage (Disney et al., 2022). User-friendliness, having multiple sources of information, and the accessibility to information are further limitations with BIM (Disney et al., 2022). Furthermore, companies have had the perception of being oversold the benefits of BIM which may create a sense of reluctance towards it (Disney et al., 2022). The use of time-coupled BIM in particular is often limited to smaller project since it requires a lot of manual work translating to many hours of extra work to prepare the BIM for time-coupling (Zhang et al., 2022). To incorporate the takt planning with BIM, an IDM is needed to ensure that the information

deliveries are satisfactory which creates the need for an IDM to be created or atleast understand an existing one and adapt it (Melzner, 2019).

The process of creating BIM have slow phases that consists of time consuming activites like applying metadata to 3D elements (de Marco et al., 2024). This serves as barriers for implementation and is best mitigated using IDS which helps making the methodology be more efficient and precise. In today's practice, the usage of multiple software to create a time-coupled BIM representation serves as an additional barrier to implementation (Martins et al., 2022). Today it is difficult to only use one software for the whole design phase due to each discipline using their own prefered software. Reduction in the number of software seems to be a suggested solution which also has the added benefit of reducing the training needed and lower the barrier for stakeholder integration (Zhang et al., 2022). Smaller projects can get by using one tool for BIM creation, one for scheduling and then one for integrating the two disciplines, but in larger projects the amount of softwares can easily pile up. Time-coupled BIM is more common in smaller and less complex projects due to the implementation barriers that is found when trying to integrate BIM tools, management tools, and scheduling tools with each other (Zhang et al., 2022).

Furthermore, one thing that seems to be a reoccurring topic is the time intensive process of information assignment to the model for creating the time coupling (Martins et al., 2022). The use of language models can help to eliminate manual processes (Jung et al., 2024). However, the use cases of language models for BIM seem to be few with Jung et al. (2024) being one of the first in doing so.

An implementation barrier mentioned by Butkovic and Oloke (2019) is the lack of standardization for Level of Detail (LOD). A defined LOD means a defined requirement for what needs to be modeled and to what precision (Tomczak et al., 2022). Butkovic and Oloke 2019 proposed that projects use a time-coupled BIM LOD specification to be used alongside the BIM execution plan. This aims to have the specification be a matrix that is similar to what is used for UK BIM Level 2 standard. The Model Production Delivery Table, MPDT, used for UK BIM Level 2 standard, is aimed to communicate what information needs to be produced, by who and when (Dr Anne Kemp OBE, 2020). An example of this can be viewed in table 2.2. Table 2.2 illustrates an enhanced approach to a responsibility matrix for "metal doors" with two examples of level of detail.

Two examples of level of detail (Dr Anne Kemp OBE, 2020):

- Semantic Approach (apricot shading): Utilizing industry-standard groupings and object descriptions, such as the IFC schema from buildingSMART International, to improve task structuring and cross-referencing. For instance, "metal doors" is re-identified as IFCDoor

- Extra Level of Detail (blue shading): Incorporating additional details with a further breakdown to identify what property comes from what team. This method fosters direct connections between the responsibility matrix and the modeling process through consistent naming and classification.

In 2.2 each teams responsibility can be defined and the table also defines what output to review at a specific exchange.

| Task/Deliverable | Autor Task Team | | | | | Stage for exchange with Lead Appointed Party for Review | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Legend: | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 | 5 | 6 |
| R = Responsibility<br># = Input<br>1,2,3 = Party / Provider | AAA | BBB | CCC | DDD | Other Input | | | | | | |
| Doors (IFCDoor) | | | | | | | | | | | |
| 1. Internal Door Geometry Information ( IFCDoor_DOOR) | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.1 Required Door Attributes via COBierSpreadsheetML | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.1.1 All standard properties of MVB 2.4 | 1 | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.1.2 <Minus> "SeriualNumbers" | | | | | | | | | | | |
| 1.1.3 <Plus> "FireRating" | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.1.4 <Plus> "AcusticRating" | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.1.5 <Plus> "FireExit" | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.2 Required Door Properties via IFC Step | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 1.2.1 All standard properties of MVD RV 1.2 | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 2. Acess Hatch Geometrical Information (IFCDoor_TRAPDOOR) | R | | | | | | 1 | 1 | 1 | 1 | 1 |
| 2.1 Required Door Attributes via COBie SpreadsheetML) | R | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 2.1.1 All standard properties of MVD 2.4 | 1 | # | | | | | 1 | 1 | 1 | 1 | 1 |
| 2.1.2 <Minus> "SerialNumber" | | | | | | | | | | | |
| Metal Doors (IFCDoor) | | | | | | | | | | | |

**Figure 2.2:** MDPT matrix used for UK BIM Level 2.

LOD between schedule activities contributes to the implementation difficulty since the schedule has varying granularity for activity detailing (Jung et al., 2024). A varying granularity makes the process of pairing activities with 3D elements inconsistent. A studied reason for this granularity is that often before the execution schedule is made, a general plan is made that only answers the question if the project can be executed within the initial expected project duration (Zhang et al., 2022).

As suggested by Butkovic and Oloke(2019) a time-coupled LOD specification can be used to ensure the right quality and detailing of the data from the schedule and BIM. This still requires a lot of manual work but streamlines the work by practitioners knowing what LOD they will get.

In a study by Wu et al. (2017) of nine different BIM maturity measurement tools, they highlight that depending on the BIM creation structure different measurement tools are appropriate. Modell maturity index, MMI, can be used to control delivery of model detail throughout the entire process of a project (Björk, 2021). MMI is divided up into whole numbers of a step length of 100.

MMI steps and information required at each step (Björk, 2021):

- 100 - Concept model: Only Volume (geometry)
- 200 - Proposal model: Object names, levels, geo-spatial placement
- 300 - Detailed model: Object classification, IR, materials
- 400 - Production model: Production-related information applied
- 500 - Relation/as-built model: Production changes, product-specific information
- 600 - Management model: Maintenance information, sensory equipment

Björk (2021) claims that MMI can steer the industry away from LOD which has many different definitions. The main benefit of MMI is that it allows for projects to have a clear understanding on how detailed their model needs to be at certain stages. Furthermore, MMI allows projects to focus their efforts on the detail of BIM when it is required which ensures a coherent detail level (Björk, 2021).

Creating detailed plans adds additional workload to a project (Boton et al., 2015). When trying to create time-coupled BIM simulations, Boton et al. (2015) explains that in their experiment they had to continuously validate the proposed sequence assignment of 3D elements with the project manager and then re-import updated model and schedule as the schedule activities detail level were updated. Furthermore, Boton concludes that for the creation of time-coupled BIM simulations, practitioners are expected to manage multiple LOD due to different actors not having a common standard. Boton proposes an uniformed temporal LOD to ensure a LOD that is fit for time-coupled BIM purposes.

# 3

# Methods

This chapter aims to describe the methodology used in this thesis. It starts with an overview of the research approach, followed by a discussion of the literature review. Next, the empirical study is presented, detailing the data collection and analysis methods. The chapter concludes with a reflection of ethical considerations and the research quality.

## 3.1 Research Approach

The overall framework of the thesis is a Design Science Methodology which according to Wieringa (2010) is suitable when addressing practical problems which require solutions involving the creation and validation of applications. Wieringa continues that the methodology is especially applicable in software engineering when addressing issues in design, construction or maintenance. The method focuses on identifying practical problems and evaluating them against stakeholder criteria which is applicable to this thesis as stakeholder criteria is being evaluated by interviews.

Furthermore, the thesis utilizes a qualitative research method to explore participants' perceptions and experiences of using digital tools. According to Greener (2008), qualitative methods are usually used when exploring issues which cannot be expressed by numbers and one of the principal qualitative methods is interviews which is used in this study. Therefore the method is deemed suitable for the thesis and it is in line with the interpretive philosophy as it allows for a detailed investigation of social processes.

## 3.2 Literature Review

The literature review followed an abductive approach, which allows the development of new combinations by mixing established theoretical models with insights gained from real-world observations Dubois and Gadde (2002). This iterative process enables theory development rooted in practical experiences, which can be further refined through interviews.

The literature review was conducted to gain knowledge about the topic through previous studies and to identify areas requiring further exploration. Most of the review took place before the interviews, helping to pinpoint key issues and shape the interview questions. However, as an abductive approach was employed, additional literature was reviewed later to incorporate new perspectives and insights that emerged during the interview process.

The literature was primarily collected by searching for keywords relevant to the thesis in databases such as Google Scholar, Chalmers Library, and ScienceDirect. Keywords included *BIM, Takt, 4D, StreamBIM, Scheduling with BIM, time-coupled BIM* and *Powerproject*. To ensure relevance, the selected literature was reviewed by reading the abstracts and conclusions, and credibility was assessed by considering the number of citations from other authors.

## 3.3 Empirical Study

The empirical study consists of 10 semi-structured interviews, offering valuable material that highlights the current state of the industry and practitioners' needs. This empirical component complements the literature review, providing a broader perspective on the potential opportunities and challenges within the field. As mentioned above, the interviews were semi-structured and thus based on the interview guide in Appendix A. The initial questions were then complemented with discussion and questions about the answers given which differed from each interview. The analysis and thematization of the interviews were based on the research questions, ensuring a structured exploration of the data.

Interviews were conducted either in person or online, depending on each interviewee's availability and location. They were held in either Swedish or English to ensure the comfort and convenience of participants. Additionally, the interviews spanned from 45 to 60 minutes in duration.

Transcription of the interviews was recorded by using "Klang.AI" and a first transcription was produced by the AI. Thereafter, the transcription was read and corrected according to the sound file. A noteworthy detail about the AI transcription is that it was not correct all of the time and words are misread or misinterpreted. However, reading back and especially listening to that part of the interview, the sentences are easily corrected and results in a trustworthy final transcription. This process allowed for more time spent on analysis than on transcribing words manually which streamlined the interview process. All interviewees were aware of the usage of AI during the interview and provided consent to it, none refrained from the usage of AI.

After correcting the transcriptions, the interviews were analyzed in comparison to the findings in the literature review in order to find possible similarities and differences. The analysis from the interviews and literature resulted in interest in conducting a small case study where benefits found in the literature and interviews

were to be exemplified. This case study used StreamBIM, a construction management software, due to its takt-planning and model-focused capabilities. The model used was a 6 story building in IFC format and changes to the model was done in Revit 2023. No additional modification was done to the StreamBIM application. The main usage of StreamBIM was to filter the model by parameters of each element to create a time-coupled representation.

### 3.3.1 Respondents

To explore the specifics of time scheduling and information management, interviews were conducted with individuals across various roles, specifically selecting participants who come in contact with information management on a daily basis. This approach aimed to gather a broad spectrum of experiences and insights, highlighting diverse perspectives. Table 3.1 presents the roles of all interviewees, arranged in the order of their interviews. If an interviewee expressed that they did not want to include certain information, it is left blank.

**Table 3.1:** Lists of respondents and their respective roles, company and mode of interview

| **Interviews** | | | | |
|---|---|---|---|---|
| ***No.*** | ***Role*** | ***Company*** | ***Interview mode*** | ***Reference in text*** |
| 1. | Project Manager | Chalmers Fastigheter | Onsite | PM1 |
| 2. | Site Manager | Byggstyrning | Digital | SM |
| 3. | Development Manager | | Digital | DevM |
| 4. | Design Manager | Skanska | Digital | DesM |
| 5. | BIM-coordinator | WSP | Onsite | BC |
| 6. | Team Manager VDC | Sweco | Digital | VDCM |
| 7. | Planning Specialist | Skanska | Digital | PS |
| 8. | Project Manager | Tikab | Digital | PM2 |
| 9. | Project Manager | VGR | Digital | PM3 |
| 10. | Senior Principal Project Controls | WSP | Digital | PPC |

**Interviewee 1, PM1,** works with developing project directives, investigating costs and time frames, defining the scope and monitoring the project plan. The interviewee also works with contractors and other stakeholders to ensure that the project is carried out in an efficient and qualitative manner.

**Interviewee 2, SM,** oversees the daily operations on construction sites and works exclusively with takt planning as a planning method. They create a takt time plan, present it and revise it with the contractors, and thereafter ensure its implementation.

**Interviewee 3, DevM,** oversees project management with a focus on scheduling, digitalization, and AI, while sharing best practices across the unit and industry. With a PhD in construction operations management and international experience, they aim to improve both company and global construction practices.

**Interviewee 4, DesM,** researches how to enhance the conditions for construction through the implementation of takt production and BIM-based virtual takt planning, focusing on optimizing project workflows and integrating digital planning tools.

**Interviewee 5, BC,** is responsible for coordinating and ensuring quality of models. They also support designers and develop workflows to create the most realistic model possible.

**Interviewee 6, VDCM,** coordinates BIM-coordinators and ensure model-based requirements are integrated into tender documents and set specific tool standards. They are involved in early stages at a project management level and engage during the whole process.

**Interviewee 7, PS,** supports projects with planning and scheduling during all phases.

**Interviewee 8, PM2,** manages digital platforms and supports contractors in the use of them. They serve as both a Project Manager and BIM-coordinator ensuring that the model functions effectively.

**Interviewee 9, PM3,** works primarily with business development. They develop and improve ways of working, methods and tools for the organization.

**Interviewee 10, PPC,** works as a support to project and technical managers with scheduling, reporting to the client and internally. They have a coordinating role and help ensuring that the right things are done at the right time for the project to be completed on time.

## 3.4 Case Study

The case study combines qualitative insights from the interviews with visualizations and analyses conducted using the 3D visualization tool StreamBIM. The case study is grounded in an iterative comparison between benefits identified in the literature and practical benefits articulated by interview participants. This approach aims to validate the claims about the benefits of time-coupled BIM while identifying practical challenges and limitations.

## 3.5 Ethical Considerations

To address ethical considerations, interviewees were asked for their consent to be audio-recorded to ensure the accuracy of the material used in the thesis. They were also given the option to keep any additional information anonymous, as in some cases, individuals in specific roles could be easily identified. Each interview started with an explanation of the research purpose, scope, and the interviewee's

role. At the end of the interview, participants were told they could request changes or add more information if needed. To ensure quotes were accurate and findings were correctly interpreted, respondents could review the interview results before publication. These steps were taken to ensure participants felt comfortable and secure, and to collect high-quality data.

### 3.5.1 Discussion

A discussion was conducted to showcase the insights and reflections that emerged throughout the process, comparing findings from the literature study with those from the empirical study. It is important to note that the discussion chapter primarily consists of interpretations and perceptions rather than exclusively factual data.

# 4

# Results & Analysis

This chapter is divided into two main parts: interview results and the case study results. The results from the interviews are further divided into the chapters BIM, Scheduling, and Time Coupled BIM. Analysis is done first between the literature and the interviews, and then the case study builds upon that analysis. As such, the results of the case study are presented after the analysis of the interviews and the literature.

A summary of the responses from the interviewees regarding their understanding and use of BIM, their familiarity with takt planning, and their overall attitude toward time-coupled BIM is is presented in Table 4.1. The BIM Definition column captures how each role defines BIM, ranging from a design-phase methodology to a data-rich or lifecycle-centered model. The BIM Interactivity column indicates whether interviewees actively use BIM in their daily work. The Knowledge of Takt Planning column reveals whether interviewees are aware of this planning methodology. Lastly, the Attitude Towards Time-Coupled BIM column shows a generally positive outlook on its potential benefits, though several interviewees highlight the significant work needed before its full advantages can be realized.

**Table 4.1:** Summary of Interviewees' BIM Perspectives, Interaction Levels, and Views on Time-Coupled BIM

| Role | BIM Definition | BIM interactivity | Knowledge of takt planning | Attitude towards time-coupled BIM |
|---|---|---|---|---|
| PM1 | Method used in the design phase | - | - | + |
| SM | Data-rich model of a building | + | + | + |
| DevM | Structured information | + | + | + |
| DesM | Combined information about building lifecycle | + | + | + |
| BC | Compiling information | + | + | + |
| VDCM | Data-rich 3D model | + | + | + |
| PS | Model with information | + | + | - |
| PM2 | A way of providing information | + | + | - |
| PM3 | Centralized information | - | - | - |
| PPC | Build models and manage interfaces | - | + | - |

## 4.1 BIM

The interviewees were asked how they would define BIM and to what extent they use BIM in their work. Many claimed that the word have strayed from the abbreviations original meaning, Building Information Modeling, and have become a collective word for building information. DesM said that even though BIM is tightly connected to 3D models, for their definition, BIM does not have to be related to a 3D object. PM1 views BIM as a commonly used tool for production planning.

DevM mentioned in their definition of BIM that the building information model have information on what needs to be built but also regarding the process of building the building. The interviewee continued that BIM can be broadened to include the whole life-cycle of a building. It is not only information on what the final result for construction will be, but also information on what changes were made and for the BIM to serve as a basis for maintenance of the building.

As a planner, PS interprets the BIM and drawings and then relate that to the company's internal document to create the planning of the building, but the BIM serves mostly as additional input and the internal document together with experience and consultation are the main deciding factors.

BC said that they would like to see a broader use of BIM for things that are solely found in PDF documents today. An example of this would be to add general regulations to the BIM model instead of it being an unconnected file.

A few concerns with BIM were raised during the interviews. Both PM1 and PM3 agreed that in cases where BIM does not exist from the start, such as renovation of existing buildings, it is difficult to know if you should even spend time creating a BIM as the lack of documentation makes it time consuming. Regards to too many applications used, PM2 said that they see a current challenge in the creation of BIM for today's usage with the amount of software used and also their interoperability to communicate with each other. One example is that elements created in Magi-CAD, a construction CAD software, does not transfer "one-to-one" to Revit.

### 4.1.1 Requirement Specifications

DesM explained that effective requirement specification is essential for ensuring that project deliverables are aligned with the clients needs. The interviewee also stated that current standards such as BSAB and ISO certifications can manage three dimensions well, but they are not optimized for handling the fourth dimension within the same framework. Furthermore, it was highlighted that, it is not uncommon for the requirement specifications to not translate to client needs. To mitigate this, DesM explained that it is crucial for clear communication among stakeholders throughout the requirement-phase. The building information can aid this process by providing both visual but also contextual information.

PM1, being a client, highlighted the importance of understanding the digital tools that the contractor uses and to adapt their own requirements accordingly. Moreover, the interviewee said that good communication between decision-makers and contractors is very important. PM3 also mention that a key part of a procurement is to have a mutual understanding of a project with the contractors. The interviewee explained that they have manuals and routines for their procurement process which is constantly being revised to fit the organizations needs. This revisions centers not only around work-processes but also juridical matters. One part that they have become better at is ensuring a good delivery in the design process that fulfills the needs for management after the construction is done.

This is something that SM emphasizes as one of the key challenges of using BIM. The interviewee states that it is a challenge getting designers to create accurate drawings and focus on where it's most critical to apply their effort. The interviewee has observed designers who often overlook simple details, which can be difficult to correct once mistakes are made. For example, if a designer neglects basic elements

such as the placement of electrical outlets and the project proceeds without drawings, the outlets will most definitely end up being incorrectly positioned. PM3 have in the past experienced a knowledge gap among project managers regarding the difference between BIM delivered for construction and BIM delivered for administration and management of the completed building. Since revising their routines and requirement for the design delivery, this have been significantly improved and the project managers improved understanding of design deliverables have helped in preparing the BIM for building-management.

SM and PM3 mention their usage of BIM-manuals for specifying their requirements in the design process towards consultants. PM3 explained that their BIM-manual is centered around the final delivery that will carry over to the management phase while SM mostly focus on the production. However, SM have had cases were the client wants their help in aligning with their needs for management as well. The interviewee says that they gather information and needs from the contractors, usually on site. This way they can then update the model with the required information. This was explained to be an example on how they adapt their requirements for the model during the whole project. The interviewee explained that they would like to go with a method where they plan for revision of the design before production starts to ensure high quality but that consultants are unfamiliar with that type of structure.

DesM claims that the construction process have an efficient logical build order which the building information should be able to provide. The construction plans are made from the information from the model, therefore the information of how the building logically should be built, should already exists. SM also talks about the right order of construction and that they plan in the most logical way. SM further expressed that this understanding comes from trial and error and lessons learned from previous projects.

### 4.1.2 Level of Detail

DevM highlights the importance of level of detail in the model. When working for a general contractor, the interviewee noticed that even though sophisticated tools for calculations and planning are accessible in production, issues will arise when designers don't provide the level of detail needed. The interviewee notes that this is often partly due to the level of detail not being specified from the start. PM2 stated that the level of detail needed also depends on who the recipient of the information is. For example, the needs of detail level varies between site manager and trades worker due to needing different information for their work. Their main way of handling this is to specify in the early stages of a project what information should be presented to respectively stakeholder. This process filters the information for each level but the LODs are created from a very high level of detail to begin with.

DevM explained that model deliverables can be done under different LOD during different phases in the design phase. In the interview, LOD 300 was mentioned as a delivery level but that LOD 300 can mean different things to different designers.

Furthermore, the interviewee explained that this leads to uncertainties without good LOD definitions.

DesM mentions that it is a complex balance of having too much or too little information throughout the projects life cycle since creating information is expensive but a project needs good information for qualitative decisions. The interviewee sees a risk with too much information, it can overwhelm contractors and create a situation where they rely on experience rather than the information for the project. This leads to a situation where the information from construction does not match up with what was built, causing the building information to become as planned instead of as built.

BC also stated that more information can be too much and this requires a good information specification from the start. The interviewee exemplified this with a project that they have worked on. In that project they had three different definitions of "level" where the model contained three different values for level. They explained that this is a result of not having a good export of the IFC that is read into the program. The interviewee continued to say that the best would be to ensure that only the relevant information is present in the model. However, the work required to ensure that the information delivery is correct may not always be in the projects best interest or provide the most value for the client.

PM2 also mentioned the issue of as-planned information and said that a reason for this happening is that it is very common for issues to arise during construction which leads to solutions that stray away from the BIM. In best cases, this is documented and changed in the model. However, in the interviewee's experience, it could be a simple sketch on a PDF that never sees integration back to the original documents, or sometimes it could also be completely non-documented.

## 4.2 Scheduling and Planning

Regarding scheduling and planning projects, there are different approaches used today and the concept of takt planning does not seem to be too widespread in Sweden. The interviewees deal with time planning to a varying extent and only a few of them are familiar with the concept of takt planning.

For example, neither PM1 nor PPC, are familiar with the concept of takt planning. PM1 only carries out a very broad time plan which includes a start date, preferred end date, and a budget. More than often the project has already gone through a pre-study phase before the decision to build is made which already have established feasibility. When a contractor have been procured, the interviewees role is to monitor the project and its progress and most of the detailed planning are managed by the contractor. As mentioned in subsection 3.3.1, PPC solely works with planning and developing time plans but is not familiar with the concept of takt planning nevertheless. Both PM1 and PPC work primarily during the design phase where takt planning seem to be even less widespread.

SM on the other hand works exclusively with takt planning where they start with post-it-notes and thereafter transfer the time plan to a digital version.

### 4.2.1 The Usage of Takt Planning

SM, who uses takt planning on a daily basis, states that early inclusion of contractors is not beneficial but can be needed as the planning for a specific zone becomes more in detail. This aligns with the literature which stat is important to be flexible with the inclusion of stakeholders (Joonas Lehtovaara, 2024).Early inclusion is most beneficial and contractors should at latest be included when the takt plan starts. Additionally, they update the time plan as infrequently as possible and hold meetings only when necessary, rather than having regularly scheduled ones. Even though contractors don't need to be included in the construction of the takt time plan at an early stage, SM, DevM and DesM all stress the importance of thoroughly onboarding subcontractors, ensuring they understand the takt time plan and their specific responsibilities through comprehensive training and clear contract terms.

With regard to takt time, no universal takt time seem to exist. DesM state that a good takt time is one week which aligned with SM thoughts on a good takt rate. DevM on the other hand believed one week as a takt is a good "stroll speed" which is efficient enough while not putting too much pressure on the workers. This was elaborated upon with highlighting that a construction plan, especially when introducing takt planning, needs to be accepted by all stakeholders to be most effective. DevM has tested a few different takt rhythms and advocated for a shorter takt time. One that is three days or even one day.

### 4.2.2 Benefits with Takt Planning

SM highlights several benefits of takt planning, including a decrease in collisions and conflicts, as each discipline works within a designated zone at any given time. The interviewee also finds it easier to increase understanding in the scheduling process among stakeholders as the zoning approach makes the timeline more visually accessible. Additionally, the interviewee emphasizes that takt planning fosters a positive work environment by requiring each discipline to leave the zone clean and organized. This has been expressed as a main benefit by those who are tasked with work in a new zone as they are able to get to work faster. The visual structure of takt planning provides greater control over time and resources, making it straightforward to assess whether the project is on schedule. DesM highlights an additional benefit of takt planning which is that the set up of zones, leading to repetition of work often leads to improvement of quality.

DevM explained their experience from takt implementation in Finland. When companies first implement takt planning, they start with planning the schedule according to the takt principles. The interviewee believed that even master's degree students with little to no practical experience can do a good takt schedule, it is fairly simple. The construction companies understand how this type of planning can benefit

production quite quickly and after executing the plan, they tend to start looking into takt planning of supporting functions as well. For the interviewees first project implementing takt planning, the site managers said that from their point of view, it was a disaster and seemed really chaotic. But from big picture perspective, the project went really well and the project benefited from the implementation of takt planning as a whole. For instance, the duration of the interior phase were able to be shortened by 30-35%. The interviewee concluded that there were a lot of lessons learned and the team started thinking how much their projects could improve when they have truly mastered takt planning.

PS mention that implementation of takt planning can see some reluctance at first as you are not sure on what you are saying yes to. On the other hand, the interviewee has seen that when workers starts to follow a takt-time the work is predetermined in more detail and they start to expect a clean work space from previous trade when starting their work in each zone which makes their work more efficient.

***"Those who have tried takt, have never gone back."***

***- PS***

Another benefit that PS mentioned was that workers are pushed harder to finish in a predetermined zone, which leads to more efficient production. They exemplified this by saying that if you have a long activity that stretches over several weeks, it can be difficult to stay focused and motivated, but if you instead divide the activity into smaller zones to be completed each week, you can create a better structure and discipline in the work.

### 4.2.3 Development of Takt Planning

SM expressed that there are a lot of lessons to learn when it comes to takt planning which is something that DevM agrees with. SM state that they are very efficient in their production because of takt but they still find things to improve from each project. One such thing is the size of the takt zones which they have narrowed down to be around 300-400 square-meters. Another key learning have been to never have two wet-areas in the same zone since that created a lot of extra work. The interviewee stressed that such issues are hard to foresee, and added that on the previous project the zones naturally panned out to only contain one wet-area. When asked about knowledge sharing the interviewee stated that when they experience issues they tend to share it with their colleagues. This sharing is done mostly in an informal matter over lunch or when traveling to work, but is something that they would like to see improved. Unfortunately, the nature of the work rarely leaves time to reflect in a formal matter before the next project begins.

Further, DevM suggests that the next step in takt planning is to scale its implementation across multiple projects. Some companies have adopted a portfolio-level approach to takt production rather than focusing on individual projects. This ap-

proach enables synergy benefits, such as centralized logistics and inventory management, which minimizes repetitive efforts and optimizes resource use across projects. Standardizing processes at a portfolio level also reduces the need to retrain teams for each project, resulting in more consistent efficiency gains. Companies that have successfully implemented portfolio-level takt production report sustained productivity improvements and reductions in production time across their entire project portfolios, rather than in just a few isolated projects.

## 4.3 Time-coupled BIM

PM2 have had experience with time-coupled BIM through 4D simulations using NavisWorks. In their experience, there were mostly benefits for the client as the visualisation in real time could increase their understanding but that 3D with good filtering and the ability to measure in the model suffices for construction and for the contractors. PS encountered time-coupled BIM inside of PowerProject where the construction of the building was simulated much like a 4D simulation. One limitation to the 4D simulation, which highlights the difference between 4D simulation and time-coupled BIM, was that the user interface did not allow for filtering or sectioning of the 3D representation which lead to elements not being clearly visible. This resulted in the time-coupled addition to the BIM being neglected in the later stages of production since what was being built on site was not visible in the model due to being hidden behind other 3D elements.

DevM's perception of time-coupled BIM is mainly that it is not used that much. However, the interviewee thinks it would be very useful in weekly meetings. For instance in a situation where workers can see their area in the model and if it will conflict with any other teams during the day. Another example would be how to communicate to crews how cranes are going to move throughout the day. Moreover, potential benefits of implementing time-coupled BIM mentioned by DevM, would be for planners and designers in the planning phase to better understand how the project will unfold. However, the interviewee underscored the importance of not introducing a new tool and forcing practitioners to use it but rather introduce workflows and make them understand the benefits. The interviewee added that most of the time people will use new tools if they see the benefits and change agents need to ensure they align with the tools you want to implement.

Expanding upon this, DesM said that this technique could take 4D from being simulations to actually represent the projects sequential build process and become time-coupled BIM. The data from the model would be used as the basis for the sequencing. This process was explained to need some administrative and manual work but there are some tools and methods that can be used to automate the process. Using the coding methods BSAB and BIT are two ways of standardizing the data which eases the information coupling. VDCM mentioned that the coupling of information don't always need to be on a component level either, but it could be sufficient with coupling on zone level. Mitigating the initial manual work.

### 4.3.1 Benefits with time-coupled BIM

When asked about the benefits of a time-coupled BIM, several of the interviewees agree that visualization is a key benefit. PM1 thought the visualization would provide a very clear understanding of the projects progress which is vital since the progress is continuously reported up the management chain. Furthermore, the interviewee believed it could help with making informed decisions.

***"If the timeplan had been a model then I would have understood why things take time. And that's always good."***

***- PM1***

This was something both SM and DevM agreed with stating that time-coupled BIM would be beneficial for visualizing work in the production stage of a project. SM adds that integrating test protocols in the model could lead to significant time savings as the progress would be visualized and clear.

When talking about the importance of visual clarity between stakeholders, DesM said that a planning model where sequences of work could be visualised using the 3D model, would increase the common understanding och mitigate conflicting views of project work. PM2 and PM1 added on this, stating that the visualization could be used to ensure payments for construction progress or as a support for requesting more funding when issues in construction arises. VDCM also discussed how grounded arguments can explain the need for additional money for a project. They said that when procuring a project the client understandably wants to have a good profit margin and any additional cost is hard to motivate. However, they add that when you can show or explain to the client that it is impossible without the extra money, then they are easier to on-board.

SM perceived time-coupled BIM to benefit the contractors the most due to it giving them a better understanding if they are ahead or behind on their work. The interviewee also mentioned that an issue that they have today is that contractors purchase more materials than they need for a zone and carry that over with them to the next zone which clutters the work site. The interviewee added that there is less clutter on site using takt planning but adding time and the ability to see the site's current state and then decide where logistical elements could be best placed would be very beneficial. The reason for the over-purchasing is the low trust in the quantity take of from the BIM. With time-coupled BIM, the quantity could be validated by viewing each zone and making an informed decision if all information is present. The interviewee highlights that this becomes especially critical with large projects.

PM3 also believed the most benefits from time-coupled BIM will be most apparent during construction which is also where the most money can be saved. A mistake in the design is cheap to fix compared to a mistake in production. The interviewee continues to explain that for a client to put more money in the design phase to

allow for time enhanced BIM to be possible, there needs to be a lot of convincing and good arguments. This happened when their organisation switched from 2D to 3D and the question was always "what good would this do us? What do we as a client get out of it?". The interviewee concludes that for them to realise the benefits, someone has to not only do it first and take the first step, but also do it right and prove its worth.

### 4.3.2 Implementation difficulties

VDCM explained that a challenge with implementing new technologies like time-coupled BIM is to know if the extra information will save, or make back, the time that it took to prepare it. The size of the project is important to have in mind, larger projects have more information but smaller projects may not have the budget. PM3 expanded upon cost and have had experience from projects where the budget did not include the work, or hours, needed to maintain the information. This often relates to smaller projects like refurbishment or renovations where the budget have not considered the work needed for updating drawings and models. This results in poor documentation and a lot of work for the management of the building to update the BIM afterwards.

PS agreed with this when stating that they think that there are benefits in connecting the model with the schedule but that there needs to be more development and assurance of maintenance during the projects life-cycle. The interviewee explains that the project schedule is revised continuously and thus needs constant upkeep which is work that would be increased with the addition of connecting to the model. VDCM also mentions that a challenge with implementing time-coupled BIM is to what level of detail do you want to add the time information to. The interviewee explained that you could want the takt zones to be the highest level or it could go as deep down as individual component level. The level of detail depends on the end use-case and with higher component detail, it becomes a more technical issue and requires more work to produce.

PM2 added on this when stating that an obstacle is that there is a lot of manual work to implement time-coupled BIM especially if the project is large. When asked who would do the time implementation, the interviewee explained that it almost always falls on the contractor. In their experience, the contractor often have to adapt the information from the BIM to their needs which would also be the case for time-coupled BIM. PM3 stated that it is important for various stakeholders to be involved and have insight in the others work. Contractors and designers needs to have cross-communication and a good understanding for the whole project to mitigate delays and mistakes.

BC deemed than an obstacle to implement time-coupled BIM is on-boarding of all stakeholders. In their opinion, the workflow would change and require a more streamlined information delivery. One focus that the interviewee would have included in a time-coupled BIM implementation, which was also expressed by VDCM,

is to define what information needs to be added and how to ensure correct deliverables. VDCM added that defining a good definition of the time-coupled BIM and defining its usage in the project, would be of upmost importance in the success of its implementation.

PS had a project where they used construction simulations inside of NavisWorks but due to the limitations of the software, they stopped using the simulation feature. This was a result of them realising that after a while in production they would have to re-do the BIM which would have resulted in a lot of time and money which they were unsure if they would earn back. DevM also highlighted that it is understandable for projects to not put development money to a project if they are unsure if it will pay back. But they believed that if you can present a case to the client, or the ones holding the money, that you can be only 10% more efficient using another planning method like takt, they are not going to be hard to convince. To add on this, SM truly thinks that they save money by creating accurate 3D models with paired information. However, the interviewee continue to say that this is something that is hard to measure since each project is so unique and is never produced twice. SM explained that clients asks for them for the design and production since they have a long and good history of collaboration. The work that their company have done with digital tools, BIM specifications and quality construction management, have proved their worth to their clients.

## 4.4 Case Study of time-coupled BIM

To understand limitations and benefits of time-coupled BIM, a comparison between the benefits mentioned by the interviewees and the literature was done. This provides goals to aim towards for the case study to achieve and prove the expressed benefits. The case study deepens the understanding of the benefits by visualizing them and with the aim to show how time-coupled BIM posses these benefits. The case study also provides an understanding of limitations with the software used and the input, the BIM model, used for the study.

### 4.4.1 Illustrating the Benefits of time-coupled BIM

Visual construction scheduling was mentioned by the interviewees and seen as a key benefit to incorporating 3D elements with the time plan. Furthermore, analyzing construction issues and solving problems using time-coupled BIM was mentioned as one potential benefits from multiple interviews. SM mentioned identifying time-related collisions and also construction logistic simulations where time-coupled BIM could be used to solve the issue of logistical placements disturbing construction work. Furthermore, interviewees saw benefits to concept communication and mainly towards the client.

SM saw additional benefits which was zone related quantity take offs. Furthermore, several interviewees expressed a great benefit for cost savings or motivating budget increase using time-coupled BIM.

This results in the following list of benefits of time-coupled BIM:

- Visual construction scheduling
- Analyze construction issues
- Spatial and time related collisions
- Concept communication
- Construction logistic simulations
- Cost reduction

To understand these benefits better, the case study used a 3D visualization tool called StreamBIM to create scenarios which aims to exemplifies the benefits of time-coupled BIM. The literature and interviews emphasize the importance of understanding LOD and determining the LOD for the BIM model. Interviewee SM mentioned that even time-coupled BIM together with takt does not have to be fully detailed to be beneficial. Even zone-related time-coupled BIM would be beneficial. Hence, LOD for only time-coupling BIM with the takt zones was tested.

#### 4.4.1.1 Visual Construction Scheduling

A zone-divided takt visualization was investigated in StreamBIM. The zone-division results in only all related objects to a zone being visible. First, the isolated zone division is displayed in 4.1 and everything else is set to transparent. This leaves only the zones for the selected floor.

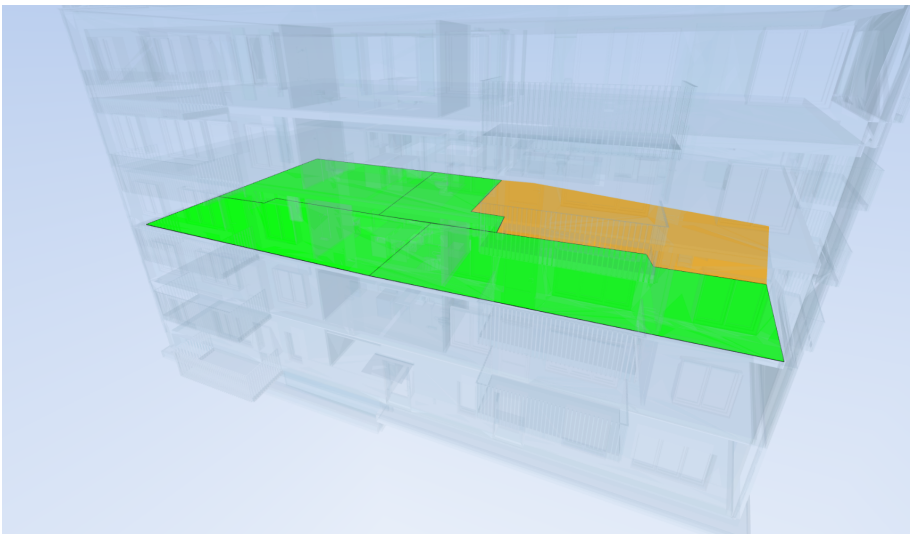


**Figure 4.1:** StreamBIM zone filtering: Filtering by all zones for one floor with zone 4 selected and highlighted

Visualing the zones in the 3D viewport using StreamBIM also has the added the benefit of keeping the 2D relation as seen in 4.2 where zones are shown on top of a plan-view of floor 4 in the building. Furthermore, Zone 4 is selected to highlight the visual communication that comes from being able to relate one zone to other zones.

**Figure 4.2:** Zone division of a building inside of StreamBIM: Top view of floor 4 and all zones for one floor

To further visualize the 3D elements related to the zone, a zoning parameter was added to the IFC file of the building in the CAD software Revit and then re-imported. The result of visualizing the zoning paramter is displayed in figure 4.3. Furthermore, an isolated view can be seen in 4.4. A limitation to the takt-zoning of the model is that elements that extend beyond the zones boundary are still visible due to model design. In the example of 4.3 the outer walls extend beyond the zone which is due to the wall being one large element. Furthermore, the filtering does not include sectioning the building in regards to the zone.

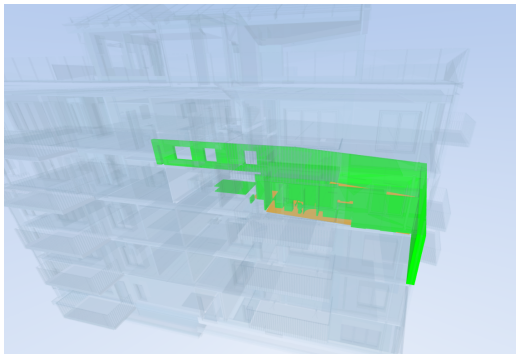


**Figure 4.3:** StreamBIM Screenshot all elements related to Zone 4 with other elements transparent

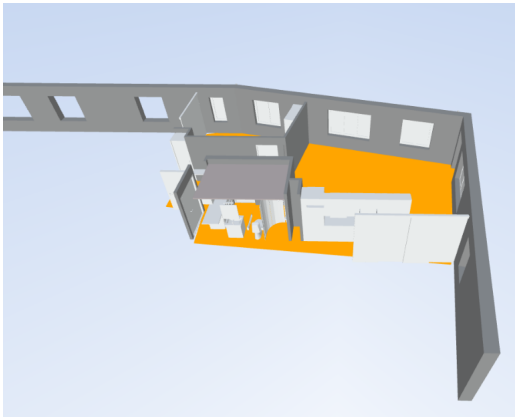


**Figure 4.4:** StreamBIM isolation of time-related elements: All elements related to Zone 4, isolated

#### 4.4.1.2 Construction & Logistic Simulations

In figure 4.5 a time-coupled element and its production related tasks are visualized. "A" highlights the production related tasks which are also connected to a takt activity. "B" shows the 3D viewport of the selected element. "C" shows the location of the element in relation to other elements for the current takt zone.

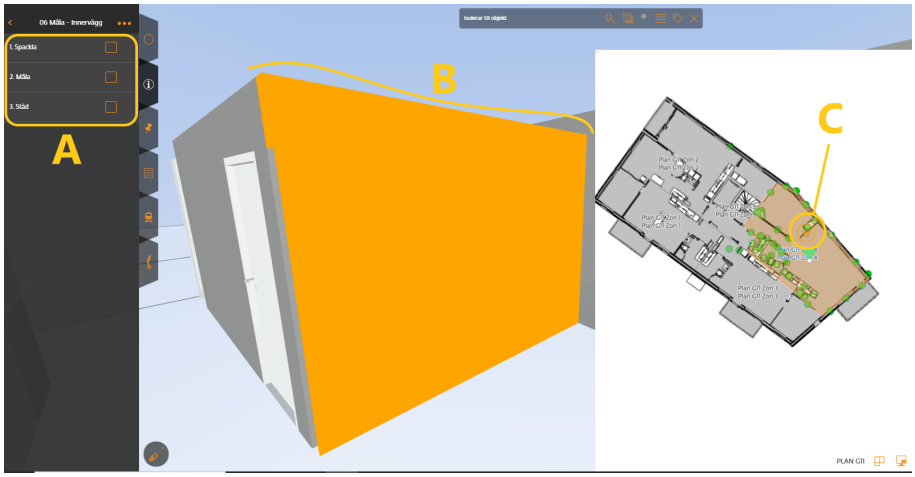



**Figure 4.5:** StreamBIM validation of constructed elements: A - Checklist in StreamBIM | B - Selected Element | C - Position in building

In figure 4.6 the same checklist as in figure 4.5 is shown from the takt-module inside of StreamBIM.

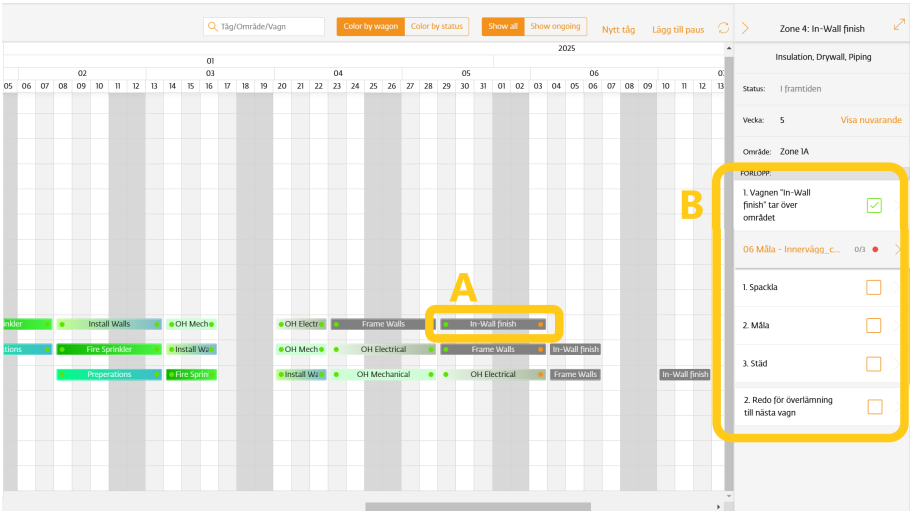
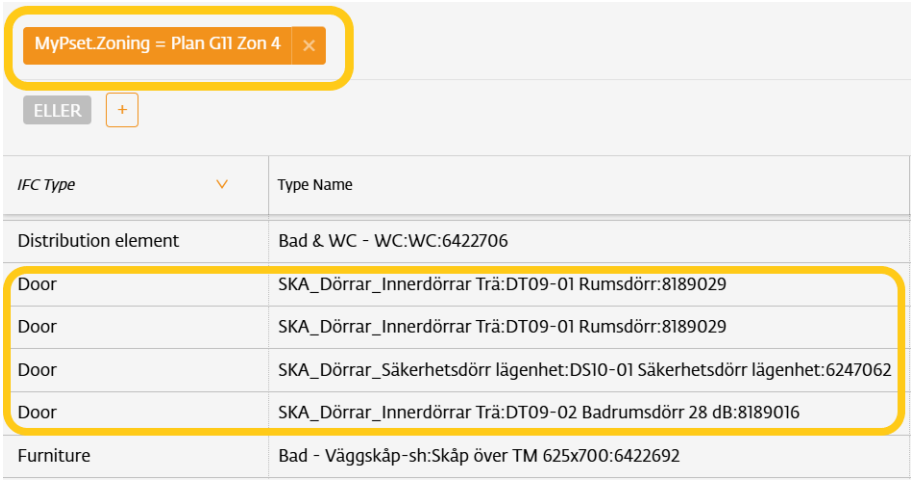



**Figure 4.6:** Takt Schedule inside StreamBIM: A - Takt activity | B - Activity Checklist

To make the task status clearer for overview visualisation, the object markers seen in figure 4.5 "C"could be paired with the color of the task status from the takt-module as seen in figure 4.6 "A". Limitation to the used software prevented the case study to include a task status connection.

Another benefit related to logistics are quantity take off. This is possible by filtering for the tasks zone-parameter as shown in 4.7. Here it is possible to identify if the correct amount of elements of a specific type is present within the zone.




| *IFC Type* | Type Name |
|---|---|
| Distribution element | Bad & WC - WC:WC:6422706 |
| Door | SKA_Dörrar_Innerdörrar Trä:DT09-01 Rumsdörr:8189029 |
| Door | SKA_Dörrar_Innerdörrar Trä:DT09-01 Rumsdörr:8189029 |
| Door | SKA_Dörrar_Säkerhetsdörr lägenhet:DS10-01 Säkerhetsdörr lägenhet:6247062 |
| Door | SKA_Dörrar_Innerdörrar Trä:DT09-02 Badrumsdörr 28 dB:8189016 |
| Furniture | Bad - Väggskåp-sh:Skåp över TM 625x700:6422692 |

**Figure 4.7:** Zone Quantity take off: Quantity take off filtered by elements within a zone. All doors within the zone highlighted

The figure above highlights all doors related to the specific zone. Zone centered

quantity take offs are smaller and, as mentioned in the interview with SM, it allows for planners to identify if anything is missing in the BIM even before construction due to the smaller data overview.

# 5

# Discussion

This chapter dives deeper into the analysis, providing deeper insights and perspectives on the subject. It is important to acknowledge that the content is mostly based on interpretations and subjective viewpoints rather than strictly factual data. As such, the discussions here should be considered with this context in mind.

## 5.1 Takt Planning

After reviewing the interviews, takt planning does not seem to be widely used in Sweden. However, SM did think it is used more than one thinks in current practices, only that the practice is not recognized as takt planning. As a lot of the literature stems from Finland and the United States, one can assume that the implementation of takt planning has come a little further in these countries or at least that the theoretical understanding around takt planning has come further.

PS mentions the ability to keep the motivation among workers high when working with a takt time plan as the goals are smaller and more tangible than goals that are several months or even years away. The clarity and visualization of a takt time plan can make workers feel ownership over the time plan due to a better understanding of their work. As explained by PS, it becomes less about billing hours and more about getting work done. The clarity additionally keeps information flowing smoothly between team members, reducing delays and making transitions between project stages easier. By maintaining a steady rhythm for tasks and meetings, takt planning enhances predictability, leading to clearer expectations and fewer unexpected issues. As both SM and PS mention, it also encourages collaboration by requiring regular coordination between different teams. This method promotes continuous communication and problem-solving. Through regular reviews and a focus on delivering complete and accurate work packages, takt planning minimizes errors and addresses issues early, reducing the need for later adjustments. Ultimately, this approach fosters a more efficient, proactive, and collaborative project environment.

### 5.1.1 Takt Planning as a catalyst for implementing time-coupled BIM

Takt Planning serves as a good introduction to implementing time-coupled BIM due to its ability to structure and organize production processes effectively using the BIM model. By dividing production into zones that are clear and manageable, takt planning establishes a framework that aligns seamlessly with the principles of time-coupled BIM.

As the production is divided into zones when using a takt time plan, teams can begin implementing time-coupled BIM with less complexity at first. Once the team is more familiar with the tools and workflows, they can refine and add details to the time-coupled BIM. Therefore, a gradual learning curve is followed. For example the connections between the model and takt time plan can be limited to all activities for one zone and not individual elements within the zone. This was tested inside of StreamBIM which shows potential for integrating time-coupled BIM into existing workflows and tools.

One of the main challenges in implementing time-coupled BIM, raised by several interviewees as well as Zhang et al. (2022) and de Marco et al. (2024), is the extensive manual effort needed to link the model with the schedule in existing softwares. The possibility to couple the information and time with varying detail was something that VDCM mentioned in their interview. The possibility of starting with a adaptable approach, where the model and schedule are connected through takt zones, before focusing on linking individual BIM components is a way to avoid unnecessary work. It also enables the development of automated methods for this integration. This strategy minimizes the reliance on manual work in existing software, making it easier to implement time-coupled BIM with less detail in the initial stages.

In the test of zone-divided time coupled BIM, the manual work required was much less than if each individual component were to be sequenced. Using the zone-division as suggested by the interviews, aligns with the literature by reducing manual work which lowers the barrier for implementation. This also relates to how DevM explained that the introduction of takt should also be done in smaller steps by starting with only "takting" the interior construction then expanding into the whole construction process. Therefore, zone-divided time coupled BIM has the potential to enable practitioners to get familiar with time-coupled BIM and then expand the usage to a more detailed level.

## 5.2 Maturity of Time-Coupled BIM

The concept of time-coupled BIM was not unfamiliar among the interviewees even though the implementation was almost non-existent. There is awareness of time-coupled BIM and some interviewees had even used it, but even people who have not tested it saw similar limitations that were mentioned in the literature. Furthermore, it is noteworthy that many interviewees addressed time-coupled BIM as 4D. This

simplification implies that it is 3D geometry without any additional information which differentiates from the purpose of time-coupled BIM. This report strongly advices to continue use time-coupled BIM instead of 4D due to time-coupled BIM being a more accurate wording. The interviewees and the literature's alignment suggests that limitations needs to be worked out to take advantage of the benefits to a greater extent. In the interview with PM3 it was mentioned that it is important that the benefits of time-coupled BIM is apparent and that eventual extra cost up-front show cost-reduction in later stages of the project. A conclusion that can be drawn from the interviews are that more pilot-projects or test cases with time-coupled BIM needs to be done to make on-boarding easier for both clients, designers and contractors. The interviewees who had tested time-coupled BIM via software like NavisWorks or PowerProject, never continued with testing again in later projects. PS who used NavisWorks mentioned that in the beginning the project saw good use of time-coupled BIM but when limitations to the software presented themselves in form of visual clarity, the use of time-coupled BIM was abandoned due to time constraints.

There is a relation between implementing time-coupled BIM and takt in the way its impact on production efficiency increases after each usage. For the interviewees who had tried takt, they stated that after each project they learned more and became better at takt, their first project often had issues but always saw increased efficiency. The interviews suggest that to mature the industry for effective time-coupled BIM, continuous efforts needs to be made in all projects so that practitioners are allowed to refine their time-coupled BIM workflow.

### 5.2.1 BIM definition

The interviewees expressed differing views on what BIM means, with many suggesting that the term has evolved beyond its original meaning of "Building Information Modeling". DesM noted that while BIM is commonly associated with 3D models, their interpretation is not limited to 3D objects. Similarly, DevM described BIM as encompassing the entire life cycle of a building, including information on changes made during construction and serving as a basis for maintenance. Meanwhile, PM1 emphasized BIM being practical to visualize 3D for production planning. These varied perspectives highlight BIM's flexibility but also suggest the potential for miscommunication among different stakeholders if expectations are not clearly defined. Even though all interviewees were very knowledgeable of BIM and many used it in their day to day work, they did not have the same view upon its definition.

### 5.2.2 Information Management Challenges

Managing the quantity and quality of information emerged as a recurring challenge. DesM explained that while comprehensive information is critical for making informed decisions, excessive detail can overwhelm contractors and lead to reliance on experience rather than the provided data. This issue is increased when information fails to align with what is actually built, resulting in "as-planned" rather than "as-built" documentation. Similarly, PM2 described instances where changes made

during construction were documented only as sketches or, in some cases, not documented at all. This lack of integration back into the BIM model harms its accuracy and utility.

Another concern, raised by BC, was the need for precise information specifications from the outset. They cited an example where differing definitions of “level” created inconsistencies within a project, a situation attributed to poorly managed information exports. Ensuring that only relevant information is included in the model requires significant effort, which may not always align with the project's immediate goals or provide the most value for the client. One can for example argue that the differing definitions of "level" is not a problem big enough for the effort required to change them if the client has not specified that the model is going to be used for maintenance or even for model based construction.

### 5.2.3 Standards and specifications

The need for clear standards and well-defined requirements was emphasized across several interviews. DesM noted that while existing information frameworks, standards for structuring information, such as BSAB and ISO certifications handle three dimensions effectively, they are less suited for integrating time (the fourth dimension) into the same structure. Misalignment between client needs and project specifications were also highlighted as a frequent issue. To address this, SM and PM3 both described the use of BIM manuals to guide design deliverables. PM3 explained that their BIM manual focuses on the final delivery for building management, whereas SM primarily considers production needs but adjustments are made to accommodate client requirements for maintenance. This shows how a well established standard for deliverables can be a way of establishing clearer communication between stakeholders.

The importance of specifying the required level of detail (LOD) early in a project was frequently mentioned. DevM emphasized that insufficient detail from designers can lead to inefficiencies in later stages. PM2 added that the level of detail required varies depending on the stakeholder, such as site managers versus site workers. Their approach involves tailoring information for each recipient, starting with a high LOD and filtering it as needed. This suggests that a high level of detail is needed from the start and that it is easier to filter out information rather than adding it at later stages.

When investigating literature related to LOD, it was stated by Björk(2021) that LOD has a wide definition and that Model Maturity Index (MMI) could create a clearer definition of model detail. LOD was mentioned during many interviews but MMI was never brought up by the interviewees, nor asked about by the interviewer. However, the DevM mentioned that in practice its hard to coordinate LOD definitions since they vary between stakeholders. The interviewee mentioned LOD 300, which is a similar system to MMI proposed by Björk (2021). This would indicate that using systems like MMI or re-defining LOD in general for projects is a valid approach to overcome uncertainties in model deliverables. Both Butkovic and Oloke

(2019) and Boton et al. (2015) proposes frameworks for standardizing LODs to more effectively allow for the implementation of time-coupled BIM. This shows the importance of LOD standards for time-coupled BIM both expressed by the literature and by the interviews.

The challenges posed by software interoperability was something PM2 noted. They stated that tools like Magi-CAD and Revit do not always communicate seamlessly, leading to discrepancies in data transfer. Such issues complicate workflows and increase the risk of errors, underscoring the need for better integration between software platforms. This aligns with the literature where Zhang et al. (2022) and Martins et al. (2022) state that wider use of different softwares leads to less interoperability for files. This shows how file formats such as IFC benefits a project by being the standard way of communicating between softwares. When using StreamBIM to test time-coupled concepts in the case study, IFC was used to export and import to Revit which allowed for good continuity in model information and showed the importance of software interoperability which is also mentioned in the literature.

The interviews also highlighted potential areas for improvement. For instance, BC suggested integrating general regulations directly into BIM models rather than relying on separate documents. SM proposed adopting iterative design revisions before production to enhance quality and alignment with project goals. Additionally, several interviewees emphasized the potential of BIM to support the entire life cycle of a building, from design and construction to operation and maintenance. This would indicate that stakeholders on various stages for a project sees benefits with BIM but encounters too many implementation barriers to fully realize its potential.

### 5.2.4 Communication and soft values

Clear communication among stakeholders was identified as essential for successful BIM implementation. PM1 emphasized the importance of understanding contractors' tools and adapting requirements accordingly. PM3 discussed the need for mutual understanding during procurement and described how their organization continuously revises routines and manuals to align with both operational and legal needs. These revisions have improved the delivery of design information, ensuring it supports building management after construction is complete. A key takeaway from both the literature and the interviews is the importance of on-boarding stakeholders and understanding their current practices to enhance rather than change.

Communication between different stakeholders will be improved by combining BIM and a takt-time plan as the construction process can be easily visualized. PM1 mentions that a time-coupled BIM visualization could help them as clients to understand if there are issues on the construction site and how that affects the outcome, possible extra costs, or extends construction. The visualization can aid the project manager in making informed and effective decisions.

SM explained in their interview that subcontractors make quantity take-offs and purchasing decisions based on the information from the BIM. In the test case inside

StreamBIM, quantification were able to be zone-defined and only contained the zone-related elements which would potentially aid the quantity take-off like SM mentioned. This exemplifies how time-coupled BIM can aid in many different aspects of construction beyond the benefits found in the literature.

The visualization does not only aid communication between stakeholders with different perspectives and in different stages. It can also help with weekly meetings on the construction site as DesM discussed in their interview. In such a meeting, workers can see their area in the model and if it will conflict with any other teams during the day giving them the opportunity to communicate and solve possible collisions beforehand. This kind of communication enables for effective work with fewer unpredicted stops during construction.

The study that was done in StreamBIM exemplified how a time-coupled visualization could be presented. The study used existing models, software and information to create a time-related representation of building progress. This test did not experience the same limitations that interviewees explained having using softwares that have explicit simulation workflows like NavisWorks and PowerProject. This could indicate that the adaptability of softwares lite StreamBIM is enabling implementing time-coupled BIM.

# 6

# Conclusion

This concluding chapter will discuss how the findings address the aim of the thesis and reflect on the achievement of its broader goals. It will provide a summary of the key results related to the research questions and conclude with suggestions for future research in the field.

This thesis set out to explore the implementation of time-coupled BIM and takt planning in the Swedish construction industry, with a focus on their effects on communication, coordination, and project management. Despite the recognized benefits of time-coupled BIM, such as improved visualization, risk management, and collaboration, its adoption remains limited in Sweden due to challenges like high implementation costs, lack of training, and limited integration of planning and modeling workflows. Furthermore, takt planning, with its spatial related and methodical approach to scheduling, was investigated as a potential enabler for broader adoption of time-coupled BIM.

The research aimed to address four primary questions: The current maturity for implementing time-coupled BIM in Sweden, the potential of takt planning as an enabler, and the effects of integrating time-coupled BIM in construction projects. These questions were formulated to better understand the challenges and opportunities within the industry and to explore how these tools and methods could contribute to more efficient and streamlined project execution.

To answer these research questions, the study employed a qualitative approach, combining a literature review with semi-structured interviews. The literature review provided a theoretical foundation, drawing insights from previous studies and identifying existing gaps in knowledge. Meanwhile, the interviews captured the perspectives and experiences of practitioners across various roles in the construction industry. This approach allowed for a comprehensive analysis, combining theoretical understanding with practical applications. Findings from the literature and interviews were exemplified using the model centric managment tool StreamBIM.

The findings offer an insight of the current state of time-coupled BIM and takt planning in Sweden, highlighting both the progress made and the barriers that still exist. By examining today's practices and settings, the study not only sheds light on

current challenges but also provides a framework for future advancements in digital construction planning.

## 6.1 The Maturity for Implementing Time-Coupled BIM in Sweden

The maturity for implementing time-coupled BIM in Sweden can be described as emerging but not yet fully realized. While foundational practices and awareness are in place, significant obstacles, such as the manual coupling process and the separation of planning and modeling, must be addressed to unlock the full potential of time-coupled BIM. The Swedish construction industry has already embraced the practice of adding information to 3D models meaning the integration of time as an additional layer of information builds on existing practices, providing a natural extension to current workflows. To advance maturity, the industry must prioritize developing tools and workflows that reduce manual effort and align modeling with planning. This can, for instance, be done through using specific requirements as well as stating the projects required LODs during tendering. Furthermore, to allow efficient implementation of time-coupled BIM, the industry needs to create a better understanding between stakeholders in regards to model information. Understanding and utilizing standards such as IFC is key to allow for continuity in model information.

## 6.2 The Role of Takt Planning in Sweden and Its Potential as an Enabler for Time-Coupled BIM

Takt planning does not appear to be too widespread in Sweden but seem to be more utilized than initially assumed. However, it is often used without formal acknowledgment. Compared to countries such as Finland and the United States, where literature and practices are more advanced, Sweden's adoption is still developing. However, its benefits are increasingly recognized. The interviewees highlighted how takt planning improves clarity, visualization, and motivation among workers by breaking down large goals into smaller, tangible tasks. These attributes not only improve workflow predictability and team collaboration, but also align closely with Lean construction principles, making takt planning a valuable tool in Swedish projects.

The relation between the takt time plans zones and the model makes the model more integrated than in traditional time scheduling. As takt planning offers a clear and flexible structure, it makes it easier to gradually implement time-coupled BIM utilizing a takt time plan. By dividing the production into zones, takt planning allows connecting schedules and BIM's at a broader level at first by integrating the model into the workflow of planners. When the relationship to the model is established, planners are more knowledgeable about using the model in their workflow and can

benefit from the information it contains. When planners use the information from the model more, they can set clearer requirements for the information they use to establish a production schedule. If the model already contains the information to produce the production schedule from the beginning, it becomes easier to integrate the model into time-coupled simulations or visualizations. Hence, the implementation of time-coupled BIM benefits from takt-planning due to its ability to integrate the information model into existing workflows of practitioners.

## 6.3 Effects of Implementing Time-Coupled BIM in a Construction Project

The implementation of time-coupled BIM in construction projects has several positive effects. The main effects is that it provides clear visualization of the project in real time. As a result, efficiency, safety, and cost control can be enhanced on site. The clear visualization improves communication among multiple stakeholders, ensuring everyone has a shared understanding of the project's progress and requirements. It also facilitates logistics by allowing teams to plan and visualize the use of space and resources such as scaffolding and cranes effectively.

Furthermore, time-coupled BIM can help with controlling quantities, reducing the risk of over-ordering materials. This not only minimizes waste but also helps keep the worksite cleaner, safer, and with less clutter. Additionally, the ability to identify potential clashes or logistical issues early in the planning phase enables teams to address problems proactively, saving both time and money during construction. Overall, time-coupled BIM contributes to a more streamlined and coordinated project execution.

## 6.4 Key findings

Building on the findings, this thesis highlights the potential of time-coupled BIM and takt planning in the Swedish construction industry. While the current maturity of time-coupled BIM is emerging, its integration faces challenges that require industry-wide efforts, including improved tools, streamlined workflows, and better stakeholder alignment around information management. Takt planning, with its spatial related approach, demonstrates significant potential to facilitate the adoption of time-coupled BIM by gradually integrating the model into practitioners' workflows. Together, these methods enhance visualization, improve communication, and optimize logistics, resulting in more efficient, safe, and sustainable construction projects. By addressing existing barriers and leveraging the synergies between takt planning and time-coupled BIM, the industry can unlock new opportunities for innovation and productivity. These findings provide a foundation for future research and practical advancements in digital construction planning.

## 6.5 Suggestions for Further Research

Further research is needed to address the barriers and unlock the full potential of time-coupled BIM in Sweden's construction industry. Key areas involve minimizing the manual effort required for coupling time components with BIM models and the lack of alignment between planning and modeling workflows. Automation presents a significant opportunity and studies could explore the development of tools and technologies to streamline this process, reducing the time and expertise needed for implementation.

Wider use of time-coupled BIM is important to clearly show its overall benefits. Future research should focus on studying projects that implement time-coupled BIM, particularly those integrating takt planning, to quantify their impact on efficiency, cost savings, and safety. Such studies would provide data-driven evidence to encourage more stakeholders to adopt these methods. Case studies and pilot projects across diverse contexts, combined with targeted education and training programs, could further enhance understanding and practical application within the industry.

Finally, standardization and interoperability must be prioritized to ensure seamless communication and collaboration among stakeholders. Research into the effective use of standards such as IFC and lessons from countries where literature and practices are more advanced, like Finland and the United States, could inform Swedish strategies. By focusing on these areas, the industry can move closer to fully realizing the benefits of time-coupled BIM, paving the way for more streamlined, efficient, and sustainable construction practices.

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# A

# Appendix 1

### Introductory Questions

- We'd like to start by asking if it's okay to include your role and company in our project?
- Please feel free to start by introducing yourself.
- What is your role?
- What does it entail?

### BIM

- Do you know what BIM is?
- How would you define BIM?
- Do you use BIM?

| **Yes** | **No** |
|---|---|
| Describe your interaction with BIM and why you use it. | Why? |
| How involved are you in model design? | Are there areas where you think BIM could be used in your work? |
| What is the process for making the model? | Is it a conscious choice not to do it? |
| What challenges do you see in creating/using BIM? | |
| What potential do you see in using BIM? | |
| How do you ensure the model contains the correct and relevant information? | |

### Scheduling

- How do you create a project timeline today?
- How involved are various actors in production on your end?
  - Do you, for example, bring in the site manager, foreman, or subcontractors for "consultation" during scheduling?
- How much knowledge is drawn from previous or other projects?
- What works well with your current planning method?
- What changes would you like to see in the planning method?
- To what level of detail is the project planned?
  - During design?
  - During production?
- Is the plan often revised?
- Have you used takt planning or are you familiar with the concept?

| **Yes** | **No** |
|---|---|
| Have you seen any positive effects from its use? | What is your routine for evaluating a schedule? |
| Are there any limitations? | Is it an active choice not to use TAKT? |
| Are there obstacles preventing everyone from understanding it? | Are there limitations preventing you from using it? |
| | Do you see disadvantages that make you refrain from using it? |

**Time-coupled BIM**

One application of BIM is linking the model to a schedule. Is this something you have done or think has potential?

| **Informed person** | **Not informed** |
|---|---|
| Please describe how you use 4D | Do you use/rely on the model to create the schedule? |
| What advantages do you see? | Do you think linking schedule and model is a good idea? |
| What limitations are there? | Is it a conscious choice not to use it? |

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