Identifying And Developing Prerequisites For Takt Planning In A BIM-Based Construction Process

Identifying And Developing Prerequisites For Takt Planning In A BIM-Based Construction Process

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ABSTRACT: *The construction industry is undergoing a significant shift in how design and production are conducted. Building Information Modeling (BIM) has emerged as a key tool for coordinating information from all involved disciplines and providing a more holistic view of the construction process. However, effective coordination and communication between different professions remain major challenges that require new approaches to project management. Takt planning has gained increasing attention as a potential solution to improve traditional planning methods. Despite this, there is a lack of real-world studies exploring BIM and takt planning where information is structured according to takt planning. A takt planning structure for all BIM-models would bring a more holistic understanding of what is to be done, controlled, and reported back. To address this gap, this paper presents findings from a three-stage research process. Firstly, form a focus group of disciplines to find a shared structure to present the execution in a common way for design and construction in a lab environment at a conceptual level, secondly implementing it to the detailed design information for real -world case project in workshops and group meetings with the focus group and then thirdly, evaluate it in the case project with the site staff involved. The findings highlight the importance of a shared denominator to get a holistic approach to project management and enabling takt planning throughout all phases of construction, providing insights into its practical application and benefits for the construction industry.*

KEYWORDS: *WBS; Building information modeling (BIM); Project Management; Takt planning.*

1. INTRODUCTION

The construction industry is undergoing a significant shift in how design and production are conducted, this also affects how projects are documented and handed over once finished. This shift can be seen as a digital transformation, with a strong focus on technologies (e.g. Howard et al., 2002; Samuelson & Björk, 2014). A key in this transformation is the emergence of Building Information Modeling (BIM) for coordinating information from all involved disciplines and providing a more holistic view of the construction process (Azhar, 2011; Sacks et al., 2018). BIM can also alleviate information loss that occurs in conventional non-digital workflows (Borrmann et al., 2018, Chapter 1; Sacks et al., 2018). Thus, BIM is seen as a major contributor to the digital transformation of the industry (Samuelson & Stehn, 2023). While there are some projects moving from drawings towards a model-based construction and process (Disney et al., 2021; Gaunt, 2017), there is still a reluctance to fully adopt BIM and thus slowing change.

One factor identified as barrier to change is the fragmentation and high specialization of the construction industry, where a disconnect between design and construction phases contributes to the fragmentation (Cerezo-Narváez et al., 2020; Mohd Nawi et al., 2014), and the prevailing project conditions preserves roles, processes, value chains and working methods within individual companies and prevents change (Samuelson & Stehn, 2023). Traditionally, construction projects mostly follow a waterfall principle where information in each phase is adjusted and modified for respective phase (Leicht et al., 2020). Furthermore, the high fragmentation and specialization amongst subcontractors is identified as potential factor for projects overshot budgets and schedule overruns occur (Nepal & Staub-French, 2016). Work Breakdown Structure (WBS) can help in defining and structure the project (Makarfi Ibrahim et al., 2009). Cerezo-Narváez et al. (2020) stresses that by using a well-developed Work Breakdown Structure (WBS), that integrates the Cost Breakdown Structure (CBS), a more representative project schedule and budget can be produced, as well as project roles and responsibilities can be assigned to subcontractors more easily. Furthermore, Cerezo-Narváez et al. (2020) also emphases that there is a lack in alignment between WBS and CBS and that a more structured work management is essential, especially in the digital management of projects. Thus, a standardization of classifications could enable integration of the WBS and CBS and ensure a connected information flow. Jung and Kang (2007) notes that standardization of the WBS could contribute to a wide set of project control systems, such as scheduling, cost control, materials management amongst other construction business functions, this confirms similar conclusions shown in Garcıá-Fornieles et al. (2003), which also adds responsibility assignment and information management to the list. Therefore, there is a need to find shared information and classification structure to enable a flow of information from design to production and all the way to operations and maintenance (O&M). There is a lack of structuring of this in BIM data between different disciplines such as planning, scheduling and cost control (Cerezo-Narváez et al., 2020; Makarfi Ibrahim et al., 2009). Makarfi Ibrahim et al. (2009), concludes that a standardized WBS structure is missing and proceeds to develop and present a structure fitted to the UK construction sector, they also note limited possibilities for generalization of this structure worldwide and that WBS structures should be developed contextualized to respective market.

With regards to planning and control, standardized processes have been proven to be beneficial (Haghsheno et al., 2016), along with a BIM-model, the project can be divided into identifiable repetitions where Takt planning can aid in the communication and implementation of the schedule (Viklund Tallgren et al., 2022). With the rise of the use of BIM-models, research points towards a possibility to improve information flow between design and construction phases as well as improved communication and collaboration within phases, especially during planning and scheduling (Crowther & Ajayi, 2019; Nepal & Staub-French, 2016; Viklund Tallgren et al., 2021). However, there is a need for a more systematic approach to the coding of models to be able to use them throughout design and construction phases.

Thus, there is a need to support processes spanning over both design and construction, and through to O&M. Both internationally and nationally there are numerous examples on standards to address increased digitalization in construction, such as CoClass which is supposed to replace the older BSAB in Sweden, Cuneco Classification System in Dennark, Uniclass in the UK and the North American Architectural, Engineering and Construction industry system OmniClass for example (Cerezo-Narváez et al., 2020; Eckerberg et al., 2016). CoClass was developed to carry information about classes, properties and activities connected to different construction related processes. A sub-set of information created in one such process is a model view definition (MVD), governed by the information delivery manual (IDM).

Thus, the aim of this research is to investigate what information is needed for production control and management to integrate from the design phase to the construction phase and how this information should be structured to help understand the project and its challenges better. This paper proceeds with this question, and addresses the general question through the following research questions:

1. Which stakeholders need to be involved from design and construction phases to find a shared common information and coding structure?
2. What are the challenges with a shared information and coding structure for design and construction phases?
3. How are the developed shared information and coding structures utilized in an actual construction project?

This paper is structured as follows; a review of related works connected to WBS, classifications and planning is shortly presented, followed by an account of the results with regards to the research questions. As a result, from the focus groups a shared coding structure was identified that extends current classification. The discussion shows that the addition of deliverables and construction scope could be used throughout the phases of the project and was found to help communication between disciplines and construction phases. The findings highlight that this type of structured information enables the prerequisites needed to increase digitalization and integration between disciplines, enabling for example a more holistic Takt planning.

2. METHODS

This research uses a qualitative approach to explore the three research questions. A combination of methods has been used to gather data. A brief overview of these methods is followed by a more in-depth description later in this section. The research was instigated through an identification of the critical stakeholders to bridge the design phase and the construction phase. These stakeholders formed a focus group. The focus group combined workshops with focus group meetings to capture context and initial requirements for the information structure. These initial meetings informed the research and development process, and two additional stages were decided to be added. The second stage concentrated on implementing and evaluating information that formed the structure. The third stage expanded the group and focused on the effects of the proposed structure. The aim of the research was to investigate what information was needed for production control during the stages from design to construction and how this information should be structured to help understand the project and its challenges better.

The focus group meetings were documented with meeting minutes and field notes. Throughout the research one single project, Hovås Tak, was used as a case.

Fig. 1: The Hovås tak apartment project (Hovås tak, Nordr, 2022)

2.1 Case Study – Hovås Tak – An Apartment building

The project used in the research was an ongoing construction of an apartment building, located in southern Gothenburg, Sweden. The house is an apartment building with two co-joined tower-blocks forming a single body, se Fig. 1. Each stairwell has four apartments on each floor with a total of 59 apartments. The building has a total gross area of 5170 m^2 with a framing of precast walls and slabs, with light steel infill walls and a non-load bearing brick façade.

2.2 The three research stages

2.2.1 Stage 1: Identifying a Coding Structure and Required Information

There are a lot of people involved in a construction project, but not everyone has the same degree of influence on how the information is structured. In the case project, Hovås Tak project, the disciplines that account for the most decisive and or governing amount of information for the design and construction management were analyzed, and a focus group was formed with these disciplines to try to find a shared structure for the information.

The focus group of ten people was represented by following disciplines:

- Client – controls the vision, the purpose of the project and what is to be built. Control the names and designations of the different parts of the building as well as documents related to the project.
- Design manager and BIM coordinator – controls the information and information structure from the designers.
- Cost manager – advises over the content of the calculation and how it is structured.
- Scheduler – controls the structure of the schedule, the content is developed together with the site management.
- Site management (Project Manager, Site Manager, Site Engineer) – advises over construction planning, logistics, purchasing, site layout plan. (i.e., the overall structure of how the project will be executed, in the more detailed planning those involved in the module will be involved)

Through workshops, the focus group tried to find ways to group and or sort the information in a way that would primarily facilitate construction planning and scheduling. The workshops were used to define coding structure and the definition of the designations *"deliverables"* and *"construction scope"* used in the case project, Hovås Tak.

2.2.2 Stage 2: Implementing and Evaluating the Coding Structure and Information

The participants in the focus group were also active in the development of the detailed design documents. This took place in parallel with the second stage of the focus group workshops. The workshops also served the purpose to create consensus of the boundaries between the deliverables and the construction scope. The designations were documented continuously to create a uniform project language.

2.2.3 Stage 3: Effects of Using the Coding Structure

The construction documents were completed in Q1 2023, and construction started in early 2023. The focus group then begun to evaluate the effects of the developed shared information structure. The group also studied how the structure affected the understanding of the project documents and how the structure was used for the more detailed construction scheduling and documentation. An expanded focus group that also involved the main contractor, Skanska's entire site organization in the case project, Hovås Tak, was established, and in a workshop the group identified the changes brought about with the newly introduced coding structure.

3. RESULTS

The workshops and focus group meetings showed that the waterfall principle was used where the information structure is adapted to each discipline on the way downstream. Upstream traceability was secondary as the focus were identifying functional requirements and compiling the cost and steering towards the set budget. During this process, it was recognized that each discipline's description of the construction work was optimized for its discipline. The information was statically presented in the form of reports, drawings, and 3D models. The site management's planning during this stage was mostly highlighting, extracting relevant amounts of information to describe the step-by-step execution of the building via a detailed job planning description and assembly drawings.

The pre-manufacturing elements were manufactured from documents based on geometries and functional requirements that existed as construction documents. A disconnect were thus created between the created construction documents and the original design documents. Traceability backwards was secondary, and this made lessons learned more difficult to document. In comparison, digitization and model-based construction made the information less static, and the information could dynamically be presented/sorted in different ways to describe different purposes.

3.1 Stage one – Identifying Coding Structure and Required Information

During the workshops, the focus group began by clarifying the vision with the information, creating an aim and purpose for the information structure. Here, the client clarified the project vision for the case project, Hovås Tak. The client stressed that it should be a "*carefully planned and well-thought-out apartment building*". This influenced all the project communication and work processes.

The next workshop challenge was to find a consensus in the project designations. In the absence of clearly communicated names of the different parts of the building, prior projects have been shown that the different disciplines create their own designations to orient themselves. For the case project, a document was created to handle the project designations, and any revisions were logged in a similar way to a building document. The marketing team was represented by the client to ensure that a clear consensus was created in the designations towards end customers, facilities management, and O&M.

3.1.1 The disciplines different information structures in the case project

During the workshop it was identified that the model structure of the designers and the structure for material take-off both are linked to building parts and functional quantities. For the case project, Hovås Tak, the main contractor, Skanska's cost calculation structure and process is based on BSAB83 (Swedish classification system from 1983), and the BIM-model's structure is based on BSAB96 (Swedish classification system from 1996). The workshops concluded that the BSAB structure worked well for technically describing building components and functional quantities. Furthermore, the various contracts that were procured was based on similar groupings of functional requirements, so documentation for purchasing was relatively easy to filter out from the BIM.

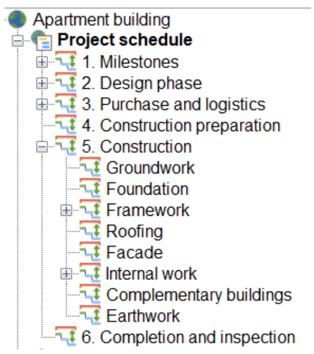

Fig 2: The schedule and time planning are based on the illustrated information structure.

The client's information structure was partly tailored for marketing to end customers and partly for O&M. The marketing material used the project designations when describing the final design of the building and the design and content of the different apartment types. The marketing language and information structure were adapted to attract the identified target customer group. O&M information was structured based on how the management of the property was planned. The client had a specific company-adapted structure for the facility management information which resembles a general BSAB structure.

The information structure of the scheduling is based on Skanska's basic scheduling template for housing projects see Fig. 2, which has been developed over the years and enables a rough comparison between projects. The site management together with a scheduler bases the schedule on this template structure and then details the phases to the specific project in accordance with the site management precious experience from similar projects.

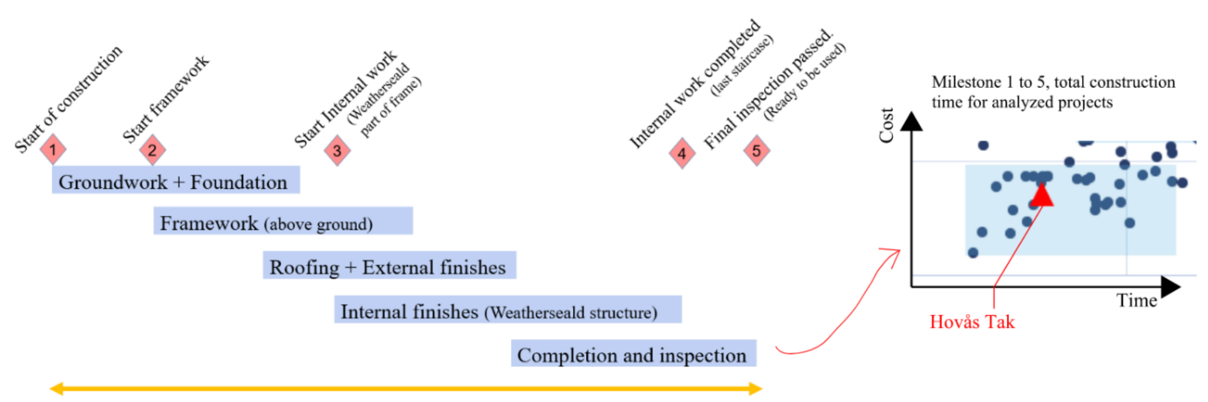

Fig. 3: When having the same WBS and coding, it is possible to analyze projects KPI's against each other to find outliers.

For a number of years now, all housing projects at Skanska extract Key Performance Indicators (KPI) for cost and time according to crucial milestones – essentially a schedule plan analysis. The general phase schedule which is used as input for the analysis is shown in Fig. 3 (left), together with the project completion date KPIs plotted for a number of individual projects (right). By using the same general structure in all projects, it is thus possible to compare KPI metrics between different apartment building projects and identify outliers or projects that must be optimized when it comes to productivity. The case project, Hovås Tak, was analyzed using this specific structure to predict and forecast performance. As seen in Fig. 3 (right) the schedule analysis places Hovås Tak at the lower end of construction time, and at the mid-range for cost when compared to similar projects (i.e., as illustrated by the lower-left rectangle).

The Construction planning was then based on an execution structure (a step-by-step completion structure), for the project. The execution structure was based on Site layout plans for the general construction phases, the master schedule, logistics and delivery schedules and purchasing schedule.

3.1.2 Shared information structure

The information of each discipline was structured to describe their vital information in an effective way. A common denominator was identified as missing by the focus group. The denominator should enable grouping of information in a similar way regardless of discipline to coordinate a shared sequential execution The focus group decided to refine the basic schedule template and the schedule analysis together with the phases in the construction planning to create deliverables that group the information in a similar way for all disciplines.

A methodology for finding the shared information structure was developed. Through an iterative process where the first loop created the first overall names and a first overall division of the deliverables of the construction phases and its geographical division were adapted to the project's conditions and scope. A side effect of this work was that as more information was generated in the project, the focus group continually helped coordinate and structure the information to create consensus in project designations and construction phases, see Fig. 4.

CoClass was identified as a possible shared coding structure. However, suitable properties were missing to get a shared structure used by all disciplines.

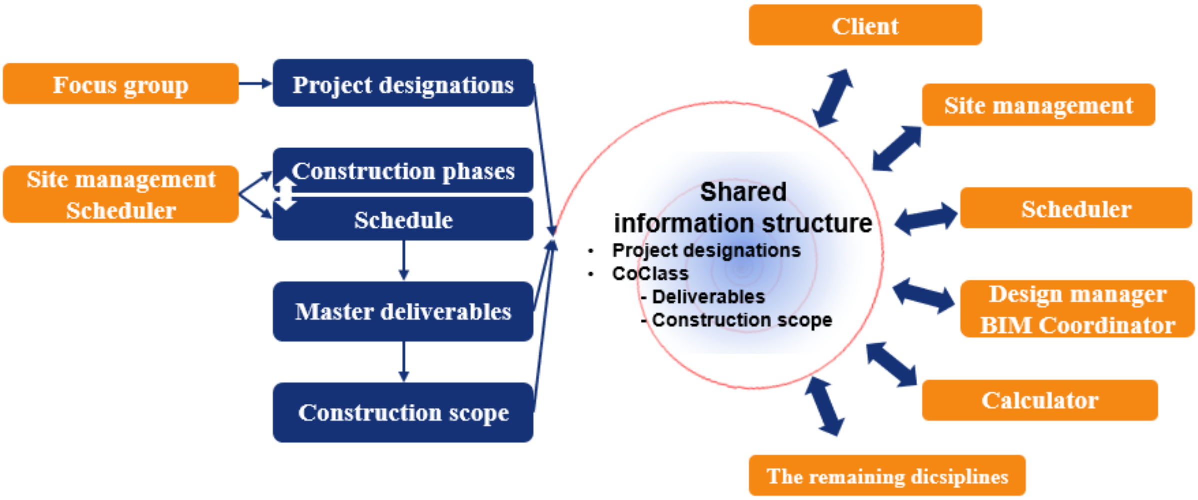

Fig 4: Illustration showing how a shared information structure for the construction project could support all the disciplines with CoClass coding of Deliverables and Construction scope.

In dialogue with Svensk Byggtjänst and the development team of CoClass, a contribution to the classification was made in the form of two new properties:

- Deliverables, "TPPR Produktions etapp" in Swedish, which is defined as a temporal object property indicating production phase.
- Construction scope, named "PRWT Produktionsdel", which can be defined as production property that specifies the spatial division of work.

By adding these two properties, the CoClass structure enables a shared structure to describe the project execution as well as the technical description for all disciplines. The case project, Hovås Tak, did not use CoClass to its full extents because existing coding structures were too tightly tied to the existing planning and cost management systems and their information structures, but the new properties were added to existing systems.

3.2 Stage two – Implementing and Evaluating Coding Structure and Information

By using storyboard form like film and sketching out a sequence of events for each construction phase, the focus group could agree on a more project-adopted division of the deliverables. The content of each deliverable was analyzed to ensure that the deliverables reflected and supported the actual execution. In particular, the focus group needed to discuss the transitions between the different deliverables for the information to be delimited in a similar way for all disciplines. The structure of the deliverables was then arranged in a hierarchy with a more comprehensive structure broken down into more detailed levels for certain deliverables where there was a need to describe the execution more clearly, see example in Fig. 5.

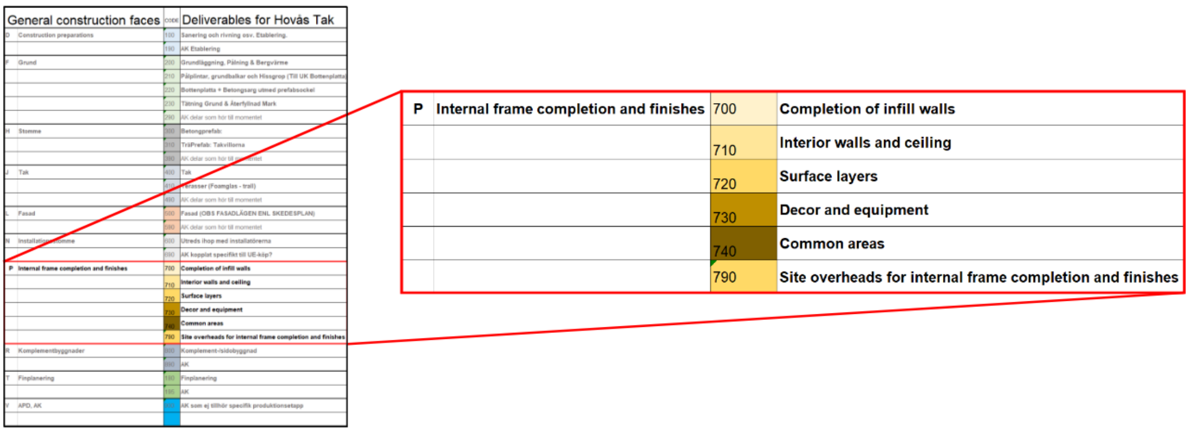

Fig. 3: Left part shows the general phases side by side with deliverables.

When the boundaries of the deliverables began to become clearer, the geographical distribution was analyzed to find a suitable material and workflow for each construction scope. This also had the effect that other disciplines could provide timely input to each other.

The construction scope was created to reflect the material flow to the specific location, the gradual execution of tasks within the scope, and provide structured information from construction for use during the O&M. Furthermore, digitization and model-based construction and takt-planning made the information less static and enabled filtering and sorting in different ways to describe different purposes.

3.2.1 Challenges

Both during design and cost management of the project the new coding structure posed challenges. In each phase it was found that the supporting systems did not easily allow mirroring of the execution process into deliverables. As a solution some composite model objects created from the classifications in the system were decomposed in more detailed functional parts to fit with the deliverables. A typical example is found in exterior walls for the case project. The design and cost management uses composite object to represent functional object of the exterior wall, meanwhile the schedule and the site management represents and complete the exterior wall in four different deliverables:

1. Construction framework,
2. Façade (external finishes),
3. Internal frame completion and
4. (internal) finishes.

While changing the systems for cost management and design was not a viable solution, a workaround was needed. This created extra administration in each discipline both in working with these WBS codes and filling them out and to work and ensure the quality of each discipline's own information.

3.3 Stage three – Effects of Using the Coding Structure

The first and foremost effect identified was the reduced language confusion in dialogue between the disciplines and how information was consumed between them. The disciplines experienced a reduced need to process and re-fit information in later stages of the construction process when the information was coded with deliverables and construction scope. By gathering construction results using this shared coding structure, a more holistic understanding of the project was formed by each discipline. Information that used to be found in different systems, sorted by different coding structures was now found more easily through the shared code structure. Additionally, disciplines could use the shared coding and information structure to ensure that they talked about the same deliverables and objects. Thus, communication between the design manager, BIM-manager, cost managers, the scheduler and site management could flow more easily.

Following are some distinct examples of how the shared coding structure simplified communication and where the combined information created more value than each piece of information on its own.

3.3.1 Schedule – presented in 3D model.

By connecting the deliverables of the models and the schedule and its construction scope, a visualization of the schedule was created directly using the BIM module in Powerproject. The visualization of the scope and content to be scheduled increased the understanding for the disciplines involved, and reconciliation of work completed became easier to review.

3.3.2 Upload quantity takeoff and easier cost control

Since the quantity takeoff from the model was already coded with deliverables and construction scope, time for the cost manager to structure the costing data was shortened. Changes in quantities were easier to identify by the focus group and updating the cost control was faster because a smaller amount of information had to be compared within a clearly defined area using the construction scope coding.

Since the cost estimate was able to be sorted based on how the case project, Hovås Tak, was to be executed, deliverables were faster reviewed and understood, and each sequence clearly visualized by the model using deliverables. The cost management could thus be linked to the degree of completion of each deliverable. Performance-based payment plans could also be linked to the work completed in each deliverable.

3.3.3 Quality work and inspection plan

The quality controls continued during the execution and ensured that the requirements were met in the finished product. With the help of the deliverables, quality risks for each deliverable could be identified. The monitoring of the inspection plan and self-inspections also became more clearly structured. The review of the inspection plan by the inspection manager together with the site organization and the various contractors was also greatly facilitated.

3.3.4 Work environment and safety risks

During the design phase, the principal designer is tasked with identifying work environment risks and as far as possible, eliminating them. The identification of work environment risks was facilitated by the simulation of the coordination of all discipline's BIM-models and construction phase schedules, gaining valuable insights into work environment risks needed to be considered in each deliverable.

3.3.5 Basis for takt planning

The sequential breakdown of the information, simulating the execution of the construction works were identified to be fully in line with the structure of the takt planning. One or more deliverables formed the basis from which work packages were created. The work packages could then be broken down into takt zones consisting of one or more construction scopes. This breakdown formed teams of disciplines that performed the work in each takt. The sequence of work in each takt zone formed a takt-train. All BIM-models follow this hierarchy and the addition of information and review of status of the BIM-model could be done continuously via each takt-wagon. By connecting the takt-planning with the model it was possible to dynamically filter and visualize the takt zones and takt-wagons for the different subcontractors.

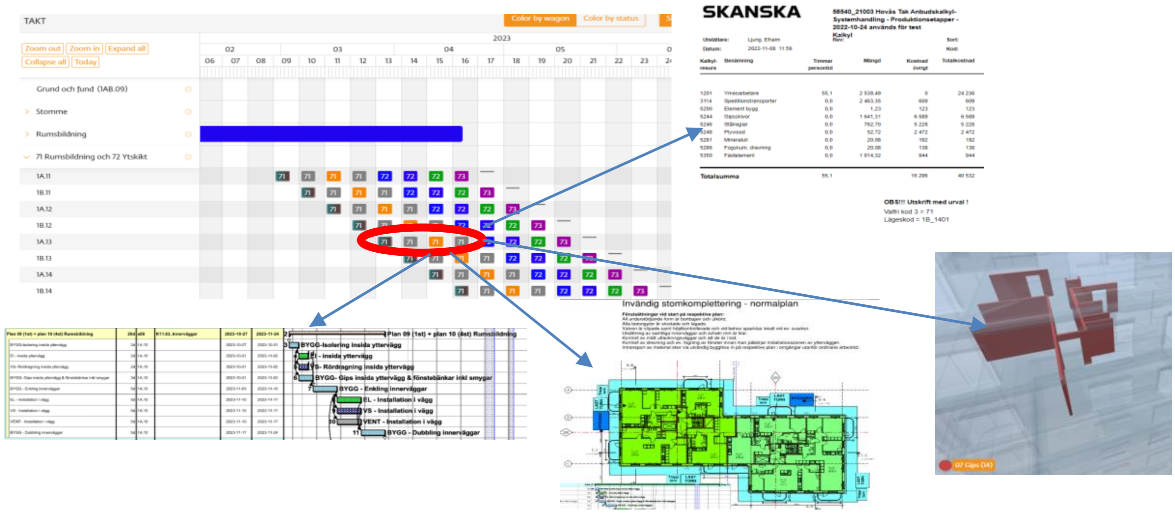

Fig. 4: By structuring of information in the project and BIM into shared code and information structure that supported and reflects how work progresses on-site, it was possible to connect the construction schedule, the cost control plan and takt schedule.

4. DISCUSSION AND ANALYSIS

The main insight during the focus group meetings were that a shared WBS and coding structure was lacking in the execution planning, similar insights has previously been presented but limitations in generalizability has been stressed (Cerezo-Narváez et al., 2020; Makarfi Ibrahim et al., 2009). Since the main contracting company recently has taken a more of a coordinating responsibility in new projects results show there is a great need to improve communication and coordination, similar conclusions are stressed in related studies (e.g., Crowther & Ajayi, 2019; Nepal & Staub-French, 2016; Viklund Tallgren et al., 2021). Thus, communication and coordination of subcontractors and designers, cost managers, schedulers and other stakeholders is as important for the project as it is for the site management.

The documentation of common language and designations eased communication process throughout the project. However, it could be argued that it is not necessary to replace the existing WBS and code structures that are well established for each discipline. The key is to bridge organization, process, technology, and information and through dialogue find common project denominators that enable the WBS and information to be grouped in shared way by different disciplines. This is supported by the conclusions and like the structure presented in Makarfi Ibrahim et al., (2009), but customized and developed for the Swedish context. Deliverables and construction scope groups the project in ways that reflect how work progresses on-site and complements the traditional description of the construction results emphasized by existing coding structures and existing WBS systems.

The traditional segmentation of work in contracts, disciplines or functions will still be needed since each area has their own needs and demands on how to ensure quality of their information and optimize their work in their systems. The traditional division works well enough for optimizing purchases and clarifying responsibilities between contracts and disciplines. The added coding of deliverables enables a more pro-active and fine-grained analysis than previously was possible. Furthermore, a common WBS and information structure enables new possibilities to the development of schedule analysis and the KPI's on the master schedule critical path. This can give a deeper insight and understanding of how different projects progress and find outliers or inefficient projects. But this data could also be used in the future for machine learning and artificial intelligence during the bidding phase or planning of new construction projects.

Another outcome from the study was that the implementation by the focus group also improved the overall work processes, where the team came together and a closer bond was formed between design, cost management and site management, lowering the threshold for communication amongst them, in line with precious research (Crowther & Ajayi, 2019; Nepal & Staub-French, 2016; Viklund Tallgren et al., 2021). One of the main insights during the implementation of the developed WBS and coding structure was that the dialogue in the focus group was especially important to ensure that information from each discipline was coded in the right way. The presentation of the visualized sequencing through the BIM-model and the deliverables created a necessary foundation for the following dialogue between design, cost management and site management. This was seen in more open discussions between disciplines, enabled through the better understanding of the holistic view of the construction scope which is in line with previous research (Azhar, 2011; Sacks et al., 2018). The extra administration the respective disciplines experienced in the coding and its structure, is thus mitigated.

By moving from static information to a digital information structure enabled information to dynamically be sorted and grouped in new ways to better suit the needs of different stakeholders. Through this common WBS and information structure, a common ground was created adding flexibility to each stakeholders' specific needs, without affecting their basic needs. Thus, it could be argued that the process gave a better understanding how different parts and resources should work together to reach a better result in the project.

Since the production of the case project, Hovås Tak, started in January 2023, the production planning and implementation of the first production stages has been conducted and evaluated. An initial reflection is that even though the information more closely followed how the construction was conducted, it was difficult for the site management and workers to absorb the information in this new way, especially in the BIM system used. With everyone used to read static drawings and descriptions; new working processes and tools had to be introduced on site. A first step to implement the common WBS structure in the site organization could be to visualize the information in each deliverable in a workshop form and discuss on how to use the information from each discipline. This enables an identification of affected stakeholders and make them understand the scope of the project while together developing the detailed job planning and construction schedule. Thus, utilizing the benefits of involving the right stakeholders in the planning and scheduling, as seen in Viklund Tallgren et al. (2021).

The sequential division in different deliverables enables the construction team to focus on one thing at a time, thus ensuring that each deliverable reaches each respective goal, quality wise as well as budget wise and schedule wise. As the information is coded and structured in a way that easier enables the site management to sort and review information regardless of discipline, the site management is enabled to:

- Clarify the coordination of material flows and logistics for each deliverable.
- Clarify responsibilities connected to the project's execution as well as coordination of sequencing of the project in general as well as during takt zones.
- Clarify cost flows and performance-based payment plans sorted by deliverables.
- Create a good basis for quality control within each deliverable.
- Create a good basis for inspection rounds and follow-up of work done for deliverable.
- Create good structure for all types of implementation statistics such as work environment, deviations from initial project scope and schedule.
- Get a good structure for the collection of operation and maintenance data and a basis for as-built documentation.

Furthermore, the deliverables enable a standardization and identification of repetitions that also can form the basis for the takt planning, as highlighted in Haghsheno et al. (2016). In the case project, the deliverables were analyzed to build effective teams that work together to reach the common goal of the finished deliverable and where the construction scope was analyzed to create optimal takt trains. The common WBS structural hierarchy in deliverables and construction scope means that the information generated in the execution can be easily linked with the information sources (construction document, production estimates, schedules, and production planning such as purchasing and logistics). In a way the coding structure standardizes information expressed as missing in prior research (Cerezo-Narváez et al., 2020; Makarfi Ibrahim et al., 2009). Furthermore, the information gap between project stages indicated in Borrmann (2018) can be avoided in with the use of shared coding structures as brought forward in this research. Project documentation, facility management documentation and O&M instructions that normally tend to be based on how it was planned to be built and function, can now reflect as built.

Knowledge transfer with regards to finance, quality, productivity, becomes administratively simpler when all information is sorted with a shared structure and coordinated to get a better overall picture. The risk of some area being prioritized and the rest being suboptimized is then avoided.

Also, by using a common WBS and BIM-model in this way enables data-driven pro-active decisions throughout a project. This could in the future assist the construction industry with meeting climate objectives, where informed data-driven decisions reduce waste and lower the overall climate impact in the projects. Implementing WBS through BIM, with the support of other digital technologies can improve circularity assessments, increase material recycling and reuse, and more accurately track environmental data throughout a building's lifecycle all the way to decommissioning and dismantling of building.

Furthermore, this study and the developed WBS and information structure has contributed with input to the continued development of the Swedish classification system CoClass.

5. CONCLUSIONS

This paper presents a study of the design, development, and validation of a WBS and coding structure for supporting BIM and takt-planning in the context of a real construction project, Hovås Tak (case project). The aim has been to establish a shared information structure for all disciplines and investigate; what structure is needed for production control and management from design to construction and how this structure could help project management to understand the project execution and its challenges better. By structuring the WBS and its information in the BIM it was possible to support and mirror how work progress on-site. In this context, it was possible to connect the construction schedule, site management planning, the cost management, and the model of the project to a better holistic understanding. BIM enables the visualization of the step-by-step progression of the construction. Digitization and BIM enables detailed multidimensional WBS and coding, a shared code does not have to be governing, but a shared coding with lower common denominator can provide new interoperability opportunities between disciplines. Digitization, model-based construction makes the information less static and enables filtering and sorting BIM in different ways to describe different purposes. Furthermore, the common WBS and information structure is also an important base for a pro-active construction management and could be a base when it comes to takt-planning of the construction site and to gather information to the digital twin.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252.

Borrmann, A., König, M., Koch, C., & Beetz, J. (2018). Building information modeling: Why? What? How? In *Building Information Modeling: Technology Foundations and Industry Practice*. https://doi.org/10.1007/978-3-319-92862-3_1

Cerezo-Narváez, A., Pastor-Fernández, A., Otero-Mateo, M., & Ballesteros-Pérez, P. (2020). Integration of cost and work breakdown structures in the management of construction projects. *Applied Sciences (Switzerland)*, *10*(4). https://doi.org/10.3390/app10041386

Crowther, J., & Ajayi, S. O. (2019). Impacts of 4D BIM on construction project performance. *International Journal of Construction Management*, *0*(0), 1–14. https://doi.org/10.1080/15623599.2019.1580832

Disney, O., Johansson, M., Domenico Leto, A., Roupé, M., Sundquist, V., & Gustafsson, M. (2021). Total BIM Project: The future of a digital construction process. *Industry 4.0 Applications for Full Lifecycle Integration of Buildings*, 21–30. https://research.chalmers.se,

Eckerberg, K., Edgar, J.-O., Engström, A., Lundgren, T., Onsbring, L., Törnkvist, M., Tönne, M., Öst, T., Bruhner, N., & Lundgren, A. (2016). *CoClass och LOD Livscykeltest av CoClass-nya generationen BSAB*.

Garcıá-Fornieles, J. M., Fan, I.-S., Perez, A., Wainwright, C., & Sehdev, K. (2003). A Work Breakdown Structure that Integrates Different Views in Aircraft Modification Projects. *Concurrent Engineering: Research and Applications*, *11*(1), 47–54. https://doi.org/10.1177/106329303032818

Gaunt, M. (2017). BIM model-based design delivery: Tideway East, England, UK. *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*, *170*(3), 50–58. https://doi.org/10.1680/jsmic.17.00011

Haghsheno, S., Binninger, M., Dlouhy, J., & Sterlike, S. (2016). History and Theoretical Foundations of Takt Planning and Takt Control. *Proceedings IGLC-24*, 53–62. www.wissen.de

Howard, R., Kiviniemi, A., & Samuelson, O. (2002, June). The latest developments in communications and e-commerce - IT barometer in 3 Nordic countries. *Distributing Knowledge in Building, CIB W78 Conference*. http://itc.scix.net/

Jung, Y., Asce, A. M., & Kang, S. (2007). Knowledge-Based Standard Progress Measurement for Integrated Cost and Schedule Performance Control. *Journal of Construction Engineering and Mangement*, *133*(1), 10–21. https://doi.org/10.1061/ASCE0733-93642007133:110

Leicht, D., Castro-Fresno, D., Dìaz, J., & Baier, C. (2020). Multidimensional construction planning and agile organized project execution-The 5D-PROMPT method. *Sustainability (Switzerland)*, *12*(16). https://doi.org/10.3390/SU12166340

Makarfi Ibrahim, Y., Kaka, A., Aouad, G., & Kagioglou, M. (2009). Framework for a generic work breakdown structure for building projects. *Construction Innovation*, *9*(4), 388–405. https://doi.org/10.1108/14714170910995930

Mohd Nawi, M. N., Baluch, N., & Bahauddin, A. Y. (2014). Impact of fragmentation issue in construction industry: An overview. *MATEC Web of Conferences*, *15*, 1–8. https://doi.org/10.1051/matecconf/20141501009

Nepal, M. P., & Staub-French, S. (2016). Supporting knowledge-intensive construction management tasks in BIM. *Journal of Information Technology in Construction*, *21*, 13–38.

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). BIM Handbook BIM Handbook Rafael Sacks 1rd Edition. In *John Wiley & Sons*.

Samuelson, O., & Björk, B. C. (2014). A longitudinal study of the adoption of IT technology in the Swedish building sector. *Automation in Construction*, *37*, 182–190. https://doi.org/10.1016/j.autcon.2013.10.006

Samuelson, O., & Stehn, L. (2023). Digital transformation in construction – a review. *Journal of Information Technology in Construction*, *28*, 385–404. https://doi.org/10.36680/j.itcon.2023.020

Viklund Tallgren, M., Johansson, M., Roupé, M., & Ljung, E. (2022). Developing Support for BIM-based Takt Time Schedules for Production Control. In C. Park, N. Dawood, F. Pour Rahimian, A. Pedro, & D. Lee (Eds.), *The future of construction in the context of digital transformation and decarbonization - Proceedings of the 22nd International Conference on Construction Applications of Virtual Reality* (pp. 723–730).

Viklund Tallgren, M., Roupé, M., & Johansson, M. (2021). 4D modelling using virtual collaborative planning and scheduling. *Journal of Information Technology in Construction (ITcon)*, *26*(42), 763–782.