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BIM Derived Quantity Checks for Takt Planning Control in Interior Works

Identifying Capacity Sensitive Work Packages Through a BIM to Excel to Revit Workflow

Master's thesis in Design and Construction Project Management

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Abstract

Takt planning in construction organizes trades through defined locations and repeated work packages so that production can follow a planned rhythm. During interior works, that rhythm depends on whether the work assigned to each location can be completed within the available takt time and whether the information behind the plan remains sufficiently stable. Design changes can alter the quantity of work assigned to a zone, while planning assumptions such as productivity determine how that quantity is translated into time. This thesis examines how BIM-based quantity information can support takt planning control and revision support in interior works by making this relationship visible at the level where production is planned.

The research is framed through design science because it develops and demonstrates a planning-support artifact in response to a practical information problem. Nine semi-structured practitioner interviews provide experience of takt planning and control, while a controlled Revit prototype and an anonymized residential building model are used to develop and demonstrate the artifact. The resulting BIM to Excel to Revit workflow extracts model quantities through Revit schedules and converts them into planning information in Excel. Selected plan information is then prepared for writeback to Revit through Dynamo and CSV files.

The calculation uses one work package in one zone as the planning unit. Quantity is translated into cycle time through a productivity assumption and compared with the selected takt capacity through overload and loaded ratios. The controlled prototype demonstrated one planning unit that exceeded the complete takt period and another that remained within it while occupying part of the selected load-adjusted capacity. In the project-model application, every planning unit required one takt period under the final crew-based productivity assumptions. Loaded ratios still varied across the work packages, showing differences in the share of the selected load-adjusted capacity occupied by their calculated cycle times.

The interviews place a boundary around what this quantity-based check can represent. Practitioners described production problems that arise even when the planned workload appears feasible, such as missing prerequisites and failed handovers. These conditions depend on site control and production knowledge that are outside the quantity calculation. The workflow therefore represents the part of takt reliability that can be examined through modeled work content and the assumptions used to translate that content into takt capacity.

The theoretical contribution lies in the operational connection between BIM-derived quantity information and planning-stage takt capacity through the combined planning unit of zone and work package. Existing research provides time-based workload logic for takt planning and separate approaches for structuring BIM information for production. The workflow connects these areas by carrying BIM-derived quantities into zone and work-package capacity calculations under visible assumptions and retaining separate model and plan states for traceability. Its interpretation remains bounded by the available model condition, the selected quantity drivers, manual coding, and productivity assumptions. Repeated real project revisions were outside the empirical test.

Keywords: BIM, takt planning, interior works, quantity checks, workload visibility, production control.

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order, followed by the project-specific abbreviations in alphabetical order:

Acronym/abbreviation	Meaning
AI	Artificial Intelligence
BIM	Building Information Modeling
CSV	Comma-Separated Values
ID	Identifier
IFC	Industry Foundation Classes
MEP	Mechanical, Electrical, and Plumbing
WP	Work Package

Project-specific abbreviation	Meaning in this thesis
A	Architectural file
K	Structural file
KP	Specialized structural file group left outside the scope
V	Ventilation file
W	Heating or water / pipework file
WP01-WP08	Work Package
Z01-Z04	Apartment zone identifiers

Contents

1
Introduction

Construction production requires several trades to use the same physical areas at different points in time. Location-based planning treats the movement of work through these areas as part of the production problem because activity sequence depends on access to space (Frandson et al., 2015). The dependence becomes visible during interior works, where a following trade often needs a preceding trade to finish before the same area becomes available.

Takt planning organizes this movement through a repeated time structure. Seppänen (2014) describes a location-based approach where activities progress through production areas using equal takt-length time windows. Tommelein (2017) develops a related planning approach through work density, where the time required by trade crews is mapped across the work area. Locations with similar geometry can therefore place different demands on production when the work assigned to them differs.

The planned rhythm therefore depends on more than the geometry of the zones. A work package has to contain an amount of work that can be performed within the available time under the assumed production capacity. When a design update increases the amount of work in one zone, the duration behind an earlier plan may change even if the zone boundary and planned sequence remain unchanged. A change to the zone boundary can create a different effect by reallocating work between planning units. These relationships make quantity information relevant before a changed plan is used for production coordination.

Production-stage control addresses another part of the problem. Binninger, Dlouhy, and Haghsheno (2017) describe takt control as continued follow-up and adjustment when production conditions diverge from the planned structure. Riekki et al. (2024) show how quantitative indicators based on production progress can identify deviations during execution. The workflow developed here uses a different timing of measurement. Its overload and loaded ratios are calculated before execution from quantity, productivity, takt time, and load factor, so they describe planned capacity use under a defined assumption set.

BIM provides a potential source for the quantities behind such a check when model information can be connected to the units used in production planning. Research on BIM-based takt planning emphasizes compatible coding and information structures between model and planning data (Ljung et al., 2023; Viklund Tallgren et al., 2022). A model object or discipline schedule does not automatically correspond to a takt work package. The information has to retain both the production location and the scope of work represented by the quantity.

The thesis develops a BIM to Excel to Revit workflow around that translation problem. Revit schedules provide model quantities, while Excel converts the quantities into cycle-time and capacity checks and arranges the resulting planning units in a takt matrix. Selected planning information is prepared for return to Revit through Dynamo and CSV files. The intended calculation unit is one work package in one zone.

Development and testing took place in two stages. A controlled Revit prototype first tested the calculation and writeback logic with walls and pipes. The workflow was then applied to one apartment floor in an anonymized IFC-based residential model containing four apartment zones and eight interior work packages. The project-model application introduced several discipline files and quantity drivers that required interpretation before they could be used in the same planning structure.

The available project material contained one usable model condition and one main planning state. This allowed the workflow to demonstrate workload checking and establish a traceable relationship between the model information and the plan produced from that condition. Repeated design updates paired with corresponding takt-plan revisions were unavailable, so revision support is examined through the information structure prepared for later comparison. Performance across a completed real revision chain remains outside the empirical evidence.

1.1 Aim

The aim of this thesis is to study how BIM-based quantity information can support takt planning control in interior works by making workload visible for individual work packages within individual production zones before the plan is used for coordination.

A second part of the aim is to develop and demonstrate a BIM to Excel to Revit workflow as a design science artifact. The artifact translates scheduled model quantities into takt-related calculations and prepares selected planning information for communication back to the model. Its information structure builds on research that links BIM-based takt planning to compatible model and planning identifiers (Ljung et al., 2023; Viklund Tallgren et al., 2022).

The workflow is intended to expose how the calculated takt fit depends on the available quantity and the productivity assumption attached to that work. It can therefore distinguish a planning unit that exceeds the available period from one that still fits but occupies a larger share of the selected load-adjusted capacity.

1.2 Research question

The project-model evidence is limited to one model condition, so revision support is examined through traceability between model information and planning information. The study does not evaluate completed revision decisions across a sequence of real project updates.

The main research question is:

How can BIM-based quantity information support takt planning control and revision support in interior works?

The following sub-questions guide the thesis:

1. What design and planning changes make a takt plan difficult to maintain during interior work?
2. How can model quantities be structured by zone and work package so cycle time and overload can be checked against a chosen takt time?
3. How can a BIM to Excel to Revit workflow make overloaded or capacity-sensitive planning units visible before plan information is returned to the model?
4. How do the available project data, model structure, and planning assumptions affect the interpretation of the BIM to Excel to Revit workflow?

1.3 Scope and limitations

The study focuses on takt planning during interior works. Interior production contains repeated spaces where several trades depend on successive access to the same area, making the relationship between location and workload suitable for a zone-based takt study (Frandson et al., 2015; Tommelein, 2017). The project-model application is limited to one apartment floor in an anonymized residential building and uses four apartment zones.

The unit of analysis combines a zone with a work package. This follows the location-based structure of takt planning while retaining the production scope assigned to that location (Seppänen, 2014; Dlouhy et al., 2016). Each calculation therefore asks whether the modeled quantity belonging to one work package in one zone can fit within the selected takt capacity under a defined productivity assumption.

A simplified Revit prototype precedes the project-model application. The prototype is used to test the calculation path and preparation for writeback under controlled conditions. The project-model stage then examines how the same logic behaves when quantities have to be collected from an IFC-based structure containing several disciplines and different quantity drivers. The workbook and project implementation are described in Chapter 5, with supporting material in Appendices A and B.

Electrical work is outside the project-model application because the provided IFC set contained no usable electrical model. Commercial optimization is also outside the research scope; the calculations translate quantity into production time and capacity use without evaluating cost performance. Productivity values provide the time conversion required by the artifact and are treated as planning assumptions. They are separate from measured production rates from the anonymized project.

The project material also limits the revision claim. Several dated model states paired with corresponding takt-plan revisions were unavailable. Model_VersionTag and Plan_VersionTag were retained so later states could be distinguished, while the Version Log and Buffer Log provide places for recording planning changes. The resulting evidence concerns one model condition and the traceability structure prepared around it.

Production readiness remains partly outside the model-based calculation. Material availability, crew presence, and physical handover conditions can determine whether work begins when planned even when its calculated duration fits the takt period. These conditions are examined through the interview material and production-control literature; they are not measured by the BIM-derived quantity check itself.

2

Background

Location-based construction planning treats physical space as part of production control because different activities depend on access to the same locations over time (Kenley & Seppänen, 2010; Frandson et al., 2015). Interior works provide a clear example. Finishing trades and building-services work move through rooms or apartment areas in sequence, and a missed handover can prevent a following trade from entering the planned location.

Takt planning adds a repeated time structure to this location-based flow. Each planned work package is expected to move through defined locations according to the selected takt period (Seppänen, 2014). Differences in work content then become a capacity problem: equal periods across locations do not imply equal quantities of work. Tommelein's (2017) discussion of work density helps explain why zones with similar geometry can place different demands on the production system.

BIM works from a different information structure. Quantity extraction begins with modeled objects, properties, and discipline-specific data, while takt planning works with production locations and work packages (Monteiro & Poças Martins, 2013; Ljung et al., 2023). A quantity taken directly from a model therefore requires a planning interpretation before it can be compared with takt capacity. The central information problem is how to preserve the relationship between the quantity, the location where the work occurs, and the production scope represented by that quantity.

Production control continues after the planning-stage quantity check. Site conditions can disrupt a calculated workload that appears feasible, and actual progress may diverge from the planned rhythm. Quantity-based capacity information and production-stage control address different parts of takt reliability: the first concerns the planned work content and its assumed duration, while the second concerns whether production follows the plan under current site conditions.

3
Literature review

Research relevant to BIM-supported takt control approaches the problem from several directions. Location-based production research establishes that work has to be understood through the places where trades move, while takt research adds a repeated time constraint to that movement (Kenley & Seppänen, 2010; Seppänen, 2014). Work-density research connects the time required by a trade with the work scope and the area in which that work is performed (Tommelein, 2017). BIM research shows that model information has to be coded and interpreted for the production use it is expected to support (Sacks et al., 2010; Ljung et al., 2023). Taken together, these fields point to an information gap between object-based quantities and the location-specific work scopes used for takt planning.

3.1 From location-based planning to takt production

Construction activities take place in physical locations that are shared by different trades over time. Kenley and Seppänen (2010) describe Location-Based Management as an approach where planning, scheduling, and control are organized through locations. Frandson et al. (2015) similarly compare location-based management and takt planning as methods that use the movement of work through space as part of production control.

Line-of-Balance and Location-Based Management provide a broader production-flow basis for takt planning. A location breakdown identifies where work is carried out, while production rates describe expected movement through those locations (Kenley & Seppänen, 2010). The schedule relationship becomes operational at the handoff: delayed work in one location can affect the following activity when both depend on access to the same space.

Takt planning constrains this flow to a repeated rhythm. Seppänen (2014) distinguishes takt planning through the use of equal planned durations across locations. Each production area therefore has the same time window even when the work assigned to it differs. A work package that requires more time than the selected takt period threatens the planned handoff because the following trade expects the location to become available when that period ends.

Tommelein (2017) approaches the same production problem through work density, which maps the time a trade crew requires to complete its scope across the work area.

Two locations with similar geometry can still create different production demands when the work assigned to them differs. Spatial repetition therefore has to be considered together with the production time associated with the work inside each location.

Location and assigned work scope are both required when workload is evaluated within a takt structure. Location identifies where the production flow occurs, while the assigned scope defines the production effort that has to fit within the repeated time window. A workload check that removes either dimension can no longer represent the handoff between a specific scope of work and the location in which it is expected to be completed.

3.2 Defining zones and work packages as the planning unit

Zones divide the building into production areas through which work can move. Seppänen (2014) connects takt planning to equal planned durations across these locations, while Tommelein (2017) shows why the amount of work inside an area affects the feasibility of that rhythm. Zone definition therefore concerns the area of handover together with the work that has to be completed before the handover occurs.

Work packages describe the production scope assigned to those areas. Dlouhy et al. (2016) develop takt planning and control through levels that connect the broader production rhythm with more detailed workspace control. Their framework places detailed work organization inside a larger takt structure, providing a basis for examining production scope at the location where it has to be performed.

Combining location and work scope produces a more specific unit for workload checking. A zone identifies the production area, while a work package identifies the scope whose duration is being evaluated. The resulting question is whether that particular scope can be completed in that particular location within the selected takt period.

Tommelein (2022) formalizes this relationship in the Work Density Method, where work density provides a common time-based measure of workload across locations. The method uses the time required by a trade to complete its scope within a defined area to support workload leveling and zone definition and to determine a takt that the planned process can meet. Physical area by itself does not express the production time required within a zone; the spatial distribution of the trade's work also enters the planning decision.

BIM-based work packaging adds a production-information perspective. Isaac et al. (2017) show how model objects can be grouped into construction work packages that reflect the scopes used to organize construction work. For takt planning, this grouping is relevant because quantity information has to remain associated with the production scope that moves through the defined zones.

Aggregated totals lose part of that relationship. A quantity for an entire trade can indicate total work without showing where the demand occurs, while a total for one zone combines production scopes with different productivity conditions. The combination of zone and work package retains both dimensions and allows each planning unit to be translated into a duration before it is compared with the takt period.

3.3 From takt plans to executable work

A planned duration says little about execution if the work lacks the conditions required for production. Ballard and Howell (1998) describe shielding production through the quality of work assignments, including whether work is sound, properly sequenced, and appropriately sized. Within a takt structure, these conditions affect whether a work package can begin and finish during the period assigned to it.

A takt matrix can therefore represent planned timing while the corresponding production assignment remains unready. A work package may have a zone and period assigned even though an unresolved design issue prevents the work from being defined or the preceding activity has left the location unavailable. The schedule position and the readiness of the work answer different questions.

Hamzeh (2009) places constraint removal in lookahead planning between higher-level scheduling and committed work. Constraints are identified before the activity is expected to begin so that planned work enters the short-term schedule with workable conditions. For takt production, this logic is closely connected to handovers because the following trade depends on the planned location becoming available at the start of its period.

Binninger, Dlouhy, and Haghsheno (2017) describe takt control as continued production control around the takt structure. Their work connects the planned rhythm with the practical task of keeping production executable as conditions change. A calculated workload check can contribute information about expected duration, but readiness still depends on whether the site conditions required by the work are present when the takt period begins.

Duration fit and production readiness describe separate conditions for reliable takt execution. Duration fit concerns whether the planned amount of work can be completed within the available takt time under an assumed production rate. Production readiness concerns whether the conditions required to start and continue that work are present. A planning unit may satisfy the duration check while remaining unready for production.

3.4 Detecting and responding to takt deviations

Takt control continues after the production rhythm has been planned. Binninger, Dlouhy, and Haghsheno (2017) describe Technical Takt Planning and Takt Control as a method that links the takt structure with systematic follow-up during production. Adjustment becomes necessary when changed conditions interfere with the planned movement of work.

A deviation can become visible at the handover between trades. The preceding work may remain unfinished when the takt period ends, or the following trade may encounter a location that is unready for entry. Since the rhythm depends on repeated use of the same areas, a local problem can affect downstream work when the next activity depends on the delayed location.

Dlouhy et al. (2016) connect takt planning with several levels of production-system design, including the level where workspaces are defined. This provides a reason for examining deviations below whole-project progress. Pressure can emerge in a particular work scope and location before its effect becomes visible in an overall schedule.

Riekki et al. (2024) provide a quantitative perspective on this detailed control. Their empirical indicators use production-progress information to identify outlier trades and takt areas during execution. The timing of their measurement is different from a quantity-based capacity check made during planning. Production-progress indicators ask where actual work is diverging from the takt plan; a planning-stage ratio asks whether the planned amount of work appears to fit the selected takt capacity before production begins.

Kujansuu et al. (2020) observed instability during the early phase of takt production in their case, followed by more stable production and improved trade flow as the structured method continued. A quantitative indicator can locate where pressure appears in the planned or actual production flow, but the production situation is still required to explain the condition behind that pressure.

Binninger, Dlouhy, Steuer, and Haghsheno (2017) examine adjustment mechanisms within takt planning and control. Their work establishes that disturbances can lead to changes in how production is organized. Quantitative signals can help locate where pressure exists, while the selected response depends on the type and scale of the condition producing it.

3.5 Turning BIM quantities into production information

BIM quantities can support production planning when the information represented by model objects corresponds sufficiently well to the work being planned. Sacks et al. (2010) discuss the relationship between BIM and lean construction through uses where model information supports production needs. A model quantity gains planning meaning through the production question it is used to answer, since the same modeled value can represent one work scope well while representing another poorly.

Monteiro and Poças Martins (2013) show that BIM-based quantity takeoff depends on model authoring and the rules through which quantities are extracted. A calculated value can be technically correct for the modeled object while representing a different scope from the work whose duration is being estimated. The quantity driver is selected before the value is converted into production time because the duration calculation inherits the production meaning of that input.

Work packages also use different physical measures. Area may represent one production scope, count another, and length a third. Their numerical size has no common workload meaning because each measure belongs to a different production process. A productivity assumption converts the selected quantity driver into expected time, linking the model quantity to the work whose duration is being estimated.

Singh et al. (2020) operationalize a related quantity-to-time relationship in ViWoLZo. Quantity take-offs and trade production rates are combined to calculate work density for spatial cells used in workload leveling and zoning. Their implementation transferred take-off information through Excel and used the resulting work-density maps to examine zoning alternatives and whether a desired takt could be met. The authors identify collection of the required quantity data from BIM at cell level as a remaining development area in their implementation. Singh and Tommelein (2023) later extend the computational approach through ViWoLZo-2, where work density is calculated location by location to support workload leveling and alternative process designs.

Ljung et al. (2023) identify compatible coding and information structures as prerequisites for BIM-based takt planning. Model information and production-planning information have to refer to corresponding planning objects before they can be used together. Viklund Tallgren et al. (2022) reach a related issue in their work on BIM-based takt schedules, where model information has to connect with production-control needs.

A model prepared primarily for design coordination may therefore require additional production-oriented interpretation. Added planning identifiers or schedule logic can be needed before object-based data can be grouped at the level used by a takt plan. The quality of the resulting production information depends on the fit between model structure and the planning question.

Disney et al. (2023) discuss Total BIM as the use of model-based information on construction sites. Their work places usability of model information close to the people who plan and carry out construction work. For takt planning, reorganizing object-level quantity data into production units allows that information to be associated with the locations and work scopes used in scheduling and control.

3.6 Linking model data with work packages and design changes

Isaac et al. (2017) show why model objects and production work packages cannot be assumed to have the same structure. Construction planning may group several modeled elements into a production scope because the work is assigned and controlled as one package. BIM-supported work packaging therefore provides a way to translate object-oriented information into production-oriented information.

Takt planning adds location to that production scope. A work package moving through several locations needs both an identity for the scope of work and an identity for the location in which the quantity is performed. Compatible identifiers make it possible to group model-derived data at the same level where the takt handoff is planned.

Design change introduces a further information problem because the quantity belonging to that planning unit can change over time. Juszczyk et al. (2016) examine BIM-based design change management as a process of identifying and analyzing changes between model states. For takt planning, a model change can become relevant when it alters the work content assigned to a zone or changes the spatial structure used by the plan.

Model state and plan state are related without being identical. A changed model may alter quantities while the sequence remains unchanged. A planning decision can also alter sequence or timing while the source model remains the same. Any revision-support structure therefore has to distinguish the model condition from the planning condition if later outputs are to be traced back to the information that produced them.

Prior research covers several parts of the quantity-to-capacity problem. Work Density research combines work quantities with production rates to describe spatial workload and has developed this relationship into methods and computational tools for workload leveling, zoning, and takt planning (Singh et al., 2020; Tommelein, 2022; Singh & Tommelein, 2023). BIM-takt research establishes the need for compatible model and planning structures, while BIM quantity-takeoff research shows that the extracted quantity depends on model authoring and extraction rules (Monteiro & Poças Martins, 2013; Ljung et al., 2023; Viklund Tallgren et al., 2022). Singh et al. (2020) also identify BIM-based collection of spatially detailed work quantities as an unresolved development area in their implementation. Less detail is available on a workflow that begins with BIM-derived quantities, groups them directly into the zone and work-package units used by the takt plan, exposes the assumptions used in the quantity-to-capacity calculation, and retains the model and plan state behind the resulting planning information. That combined information path defines the knowledge problem addressed by the artifact.

4 Method

The research is framed through design science because the study develops and demonstrates an artifact in response to a practical planning-information problem. BIM models organize quantity information through model objects and discipline-specific structures, while takt planning requires workload information at the level where production is assigned to locations. Humble and Mozelius (2023) describe design science through problem explication, requirement definition, artifact development, demonstration, and evaluation. These activities provide the structure for the BIM to Excel to Revit workflow developed in the study.

A bounded case setting supplies the empirical material used to develop and interpret the artifact. Practitioner interviews provide qualitative accounts of how takt plans are defined, controlled, and changed in construction practice. The project model supplies model-based quantities and calculation inputs within an IFC-based project structure. The controlled prototype provides an earlier test where the calculation and writeback logic can be examined before the added complexity of the project model is introduced.

The research process developed iteratively as these sources became available. Literature established the concepts needed to define the planning problem, while the interviews clarified where workload checking sits among the wider causes of takt instability. Prototype development exposed the information required by the calculation and writeback path. When the project material showed that several dated model revisions were unavailable, the empirical evaluation shifted from repeated revision comparison toward workload checking and traceability within one model condition.

Project-based quantities allowed the artifact to be demonstrated and evaluated through the planning information it produced. The available material contained no repeated live revision sequence and no production-stage execution data. The evaluation consequently concerns the function and information structure of the artifact under defined assumptions. Repeated revision performance and production outcomes remain outside the evidence available for this study. available case boundary.

4.1 Research design and design science

The design problem originates in the difference between how BIM quantities and takt plans organize information. Model quantities are attached to objects or schedules, while takt workload has to be understood for a defined work scope in a defined production location. The artifact addresses that difference by translating scheduled quantities into the combined planning unit of zone and work package.

The literature review formed the knowledge base used to define this problem. Location-based and takt literature established the role of space and repeated duration, while BIM and work-packaging literature established the need for production-oriented coding of model information. Interview material contributed a different form of relevance by showing how practitioners experience workload imbalance, information maturity, and production disturbance in projects using takt planning.

Requirements for the artifact emerged from these two sources and from the development process itself. The calculation had to retain the relationship between quantity and planning unit so a change in work content could be located. It also required a visible conversion from quantity to time because different work packages use different quantity drivers. Traceability became part of the design because the project problem included later planning updates even though repeated real model revisions could not be tested empirically.

The resulting artifact is the BIM to Excel to Revit workflow. Revit provides the model-based quantities through schedules. Excel is the calculation and planning layer where quantity drivers, productivity assumptions, takt settings, and resulting ratios remain visible during development and evaluation. Dynamo and CSV files provide the transfer step for selected planning fields that can be associated with physical model elements.

Excel was retained deliberately during the research process. A more automated calculation environment could hide transformations that needed to remain visible while the artifact was being developed. Keeping formulas and assumptions accessible allowed the exported quantity to be traced into cycle time, through the capacity comparison, and into its position in the takt matrix. This visibility served an evaluation requirement of the study and does not establish Excel as the preferred implementation for other projects.

Demonstration took place in two stages. The first stage used a controlled Revit model containing walls and pipes so the workflow could be tested with an area-based and a length-based quantity. The second stage introduced the anonymized residential model, where the same logic had to handle eight interior work packages and several discipline files. The project-model stage added model interpretation and production-oriented quantity selection to the conditions already tested in the prototype, allowing the same planning-unit logic to be examined under a more varied information structure.

Evaluation focused on whether the artifact produced the intended planning information within the available case boundary. The controlled prototype tested the calculation and writeback chain, while the project-model application tested whether a more complex IFC-based structure could be translated into comparable planning units. Live production performance and repeated completed revision cycles were outside the available evidence, so the design science evaluation concerns artifact function and information structure under the tested conditions.

4.2 Case setting and empirical material

The case uses interior work from an anonymized residential building model provided for thesis use. The project model is independent of the organizations represented in the practitioner interviews. One apartment floor was selected as the project-model boundary because it contained repeated apartment areas while remaining small enough for the quantity logic and planning identifiers to be examined in detail.

Three forms of empirical material support different parts of the research. The controlled prototype and project model provide material for demonstrating the artifact. Workbook and writeback outputs provide the resulting planning information through which the artifact can be evaluated. Interview material provides practitioner experience used to interpret where a quantity-based capacity check fits within wider takt planning and control.

The numerical project-model results belong to the selected floor and its assumption set. The interviews were not used as validation of those numerical values because the respondents did not work with the anonymized model used for the calculation. Their role is to provide empirical context for planning practices and sources of takt instability that the model calculation can or cannot represent.

4.3 Interview data collection

Nine semi-structured interviews were conducted from the beginning of February to the end of April 2026. Recruitment extended across this period because access to practitioners was limited. Several contacted organizations did not respond within the thesis period, while a smaller number declined participation. The respondents came from organizations in Finland and Norway and had practical experience related to takt planning, takt-based production, or digital support for such work.

Purposive sampling was used to locate practitioners with relevant experience. Initial contacts were identified through searches for organizations and individuals connected to practical takt implementation. Referral-based sampling later added respondents suggested through earlier contacts. The sample was selected to provide practitioner accounts from people with direct experience of the research topic. It does not provide statistical representation of the construction industry.

All interviews were conducted in English through Microsoft Teams or Google Meet and lasted between 30 and 60 minutes. Verbal consent was obtained before recording. The recordings were transcribed, checked against the recorded interviews, and summarized before the thematic analysis was carried out.

A semi-structured interview guide gave the conversations a common basis while allowing follow-up questions to respond to each participant's experience. The guide moved from the respondent's takt background into the way zones and work packages are planned, then examined the information and production conditions that affect whether the plan can be maintained. Later questions addressed detection of problems, adjustment responses, documentation, and digital support. Appendix C contains the full interview guide.

4.4 Workflow development

Artifact development began with the controlled Revit prototype. Walls and pipes were selected because they allowed the quantity-to-time logic to be tested with two different physical measures. Revit schedules supplied the quantities, Excel performed the calculations, and the resulting plan matrix was prepared for return to Revit through Dynamo and CSV files.

The prototype established the basic information path before project-model complexity was introduced. It tested whether a scheduled quantity could retain a zone and work-package identity through export, calculation, planning, and writeback preparation. The controlled model made problems in this information path observable before the IFC-based project structure introduced additional requirements for model interpretation.

The project-model application expanded this logic to an anonymized residential model. Zone ID associated quantity information with one of the apartment production areas, while Work Package ID associated it with the trade-based scope represented by the quantity. Revit schedules were prepared by work type and discipline so exported data could be grouped into one row for each zone and work-package combination.

Excel then provided the visible calculation layer. Input sheets stored the assumptions and source data required by the model calculation. The calculation structure grouped the exported quantities and converted them into duration and capacity indicators. Output and traceability sheets prepared the takt matrix, selected BackToRevit information, and records for model or plan state. Appendix A presents the workbook structure used in the final project application.

Development remained iterative during this stage because the project model did not provide every production quantity in a directly usable form. Room-based logic could not be used reliably in the imported IFC structure, and some work packages required calculated quantity drivers. Inspection of the project information led to adjustments in the rules used to represent each selected work package, keeping the calculation aligned with what the available model could defensibly provide.

4.5 Calculations and revision logic

Cycle time translates the quantity of one planning unit into expected production duration:

$$\text{Cycle time} = \text{Quantity} \div \text{Productivity rate}$$

The productivity rate is a planning assumption expressed in the unit required by the corresponding quantity driver. This conversion allows area-, count-, and length-based work packages to be interpreted through a common time dimension even though their raw quantities cannot be compared directly.

Full takt fit is represented by the overload ratio:

Overload ratio = Cycle time ÷ Takt time

An overload ratio above 1.0 means that the calculated cycle time exceeds the selected takt period under the assumption set used for that planning unit.

The project workbook also uses a load factor to examine capacity before the full takt period is occupied. Appendix A.1 uses a LoadFactor of 0.7. The loaded ratio can therefore be written as:

Loaded ratio = Cycle time ÷ (Takt time × LoadFactor)

A larger loaded ratio means that more of the selected load-adjusted capacity is occupied. RequiredPeriods identifies whether the calculated work requires more than one takt period.

The workbook also contains a WarningThreshold setting of 0.85. The project-model discussion of capacity-sensitive work is treated separately from a formal threshold classification. The loaded-ratio pattern is used to compare the share of the selected load-adjusted capacity occupied by each planning unit under the chosen assumptions. The term capacity-sensitive describes relative planning pressure unless a specific workbook warning is being discussed.

Revision support is prepared through separate model and plan identifiers. A design update refers to a dated model revision or issued design condition that changes relevant model information within the case boundary. A takt-plan revision refers to a documented change to the planning state, such as a changed zone structure or sequence. These states can move independently, so Model_VersionTag and Plan_VersionTag are kept as separate fields.

The Version Log provides a place to record later planning changes, while the Buffer Log records planned use of the buffer. The available project material contained one usable model condition and one main plan state. These structures were consequently evaluated as traceability mechanisms prepared for future comparison; a sequence of real model and plan revisions was outside the project-model test.

4.6 Analysis procedure

Interview material was analyzed thematically using the subjects covered by the semi-structured guide as an initial organizing structure. A theme was counted when a respondent clearly described the issue in relation to takt planning, even when different terminology was used. The resulting counts indicate recurrence within the nine interviews and are used descriptively. They do not represent statistical frequencies for a wider population.

The qualitative reading retained concrete examples because recurrence alone could not explain how a planning problem appeared in practice. Cases such as conflicting trade preferences for zone size, the enlarged kitchen, moisture preventing flooring, and midweek progress checks were kept alongside the counts to show how the identified themes appeared in specific production situations.

Prototype outputs were analyzed through the relationship between quantity, calculated duration, and takt capacity. The controlled model provided one case where a planning unit exceeded the complete takt period and another where the calculated cycle time remained within the complete period while its loaded ratio expressed the share of selected load-adjusted capacity occupied. This allowed the two calculation relationships to be examined before the project-model results were interpreted.

For the project model, quantities were grouped by zone and work package and linked to the selected productivity assumptions. Cycle time, overload ratio, loaded ratio, and RequiredPeriods were then read for each planning unit. Capacity sensitivity was interpreted from relative use of the load-adjusted takt capacity and from how the pattern repeated across zones; it was not treated as a new binary success/failure criterion.

Model outputs and interview findings were brought together only after their separate empirical results had been established. The model could indicate quantity-based pressure under the selected assumptions. Interview evidence was then used to interpret whether that type of pressure corresponds with practical concerns described by practitioners and where the calculation stops representing the wider production problem.

4.7 Trustworthiness and methodological boundaries

Trustworthiness was addressed by making the relation between evidence and interpretation traceable. Bell et al. (2022) discuss triangulation as one approach used when qualitative evidence is examined through more than one source or research method. Literature, interview material, prototype outputs, and project-model outputs provide different forms of evidence in this study. Agreement between them can support an interpretation when the sources point toward the same relationship. The sources remain different types of evidence and are not treated as repeated measurements of one variable.

The artifact itself provides another traceability path. Exported schedule information can be followed into the Excel structure through zone and work-package identifiers, while formulas and assumptions remain visible in the workbook. Selected planning information is then associated with a plan version before writeback preparation. This makes it possible to inspect how a planning output was produced within the tested workflow.

Transferability is separated from numerical generalization. Loaded ratios from the project application belong to one apartment floor and one assumption set. The translation logic may be applicable to another interior scope when suitable quantity drivers exist and the model can be associated consistently with the production planning units. Whether the same implementation remains manageable at a different project scale requires further testing.

Several boundaries affect the strength of the project-model result. Productivity values are planning assumptions and were not measured from production in the anonymized project. Imported and linked model information required manual interpretation, while some production work was represented through simplified quantity drivers. The project material also lacked a sequence of dated revisions. These conditions define the evidence available for evaluating workload visibility and traceability.

4.8 Ethical considerations

Participants were informed about the study and the treatment of their interview material before recording began. Verbal consent was obtained for recording and transcription. Exact role titles, company names, and project names were generalized or anonymized where needed to reduce the possibility of identifying individual respondents.

Interview recordings and derived material were stored in a shared Chalmers OneDrive folder available only to the thesis group. The anonymized project model and related project material were handled within the same restricted research environment.

AI-based tools were used as supporting tools during the thesis process for language editing, structure checking, and preparation of selected visual material from author-provided data and instructions. They were not used to generate empirical interview data or perform the project calculations. The authors reviewed the resulting material and retained responsibility for the final research content.

5

Case description

The project-model application uses one apartment floor from an anonymized IFC-based residential building model. The floor provides repeated apartment areas with differences in size and work content, allowing the same takt structure to be applied across several comparable production zones.

Interior work was selected because architectural finishes and building-services activities move through the same areas in sequence. Eight work packages were chosen across architectural, finishing, and MEP-related work. Electrical work remained outside the case because the provided model set contained no usable electrical file.

The case evaluates a planning-support workflow for translating model quantities into planning-unit duration and capacity use, followed by the takt matrix and selected writeback information. A complete executable construction schedule for the building lies outside the case boundary.

5.1 Applying takt logic to the interior scope

The floor is divided into four apartment zones labelled Z01 to Z04. Appendix A.4 gives the areas as 79 m² for Z01, 74 m² for Z02, 61 m² for Z03, and 58 m² for Z04. The zones follow comparable apartment logic without containing identical quantities, which allows workload differences to be examined without changing the basic production-zone concept.

Eight work packages are used in the project application:

- WP01 Interior partitions
- WP02 Door sets
- WP03 Floor finishes
- WP04 Wall painting
- WP05 Ceiling painting
- WP06 Suspended ceilings
- WP07 Pipework
- WP08 Ventilation ducts

The production sequence in the final matrix is WP07 Pipework → WP08 Ventilation ducts → WP01 Interior partitions → WP06 Suspended ceilings → WP05 Ceiling painting → WP04 Wall painting → BUFFER → WP03 Floor finishes → WP02 Door sets. This sequence is a planning assumption used for the case application.

A buffer period was placed after the painting work and before floor finishes and door installation. Within the case plan, the period represents time that can accommodate drying, correction, or recovery before the final floor and door activities enter the same zones. BUFFER exists as a planning element in Excel and has no corresponding physical work package for Revit writeback.

The matrix contains 12 takt periods. Production capacity is calculated with a five-working-day takt, while the dates communicated through the plan use seven-day calendar intervals. Separating these values allows labor capacity to be based on working days while the written start and end dates continue through the calendar.

5.2 Model files and quantity drivers

Quantity information was collected from four discipline files. The architecture file supplied apartment areas and most architectural elements. Structural wall information contributed to the wall-painting calculation where relevant. Ventilation ducts came from the V file, while pipe lengths came from the W file.

WorkPackageID	WorkPackageName	SourceFile	SourceCategory	QuantityDriver	QuantityUnit	BackToRevit
WP01	Interior_Partitions	A	Walls	Area	m2	Yes
WP02	Door_Sets	A	Doors	Count	nr	Yes
WP03	Floor_Finishes	A	Floors	Area	m2	Yes
WP04	Wall_Painting	AK	Walls	LengthPaintHeight*SideFactor	m2	No
WP05	Ceiling_Painting	A	Ceilings	Area	m2	No
WP06	Suspended_Ceilings	A	Ceilings	Area	m2	Yes
WP07	Pipework_Internal	W	Pipes	Length	m	Yes
WP08	Ventilation_Ducts	V	Ducts	Length	m	Yes

Table 5.1: Model files and extracted planning information.

KP files were left outside the workflow because their content fell outside the selected interior work-package structure. The available file set also lacked usable electrical information, which is why electrical work was excluded from the project application.

Revit schedules were used to expose the selected model information as tabular quantity data. The exported schedules retained the identifiers needed to associate each quantity with its apartment zone and work package before the data entered Excel.

The quantity driver differs between work packages because the physical work is represented differently in the model. Interior partitions use wall area, doors use count, and floor finishes use area. Suspended ceilings use modeled ceiling elements, while pipework and ventilation use linear quantities. These drivers are kept because the productivity assumption attached to each work package uses the corresponding unit.

Painting required additional interpretation. Wall painting was calculated from paint-relevant wall length together with paint height and a side factor, using relevant architectural and structural wall contributions. Ceiling painting used apartment-zone area because the modeled ceiling objects represented only part of the surface intended for painting. Reliable room creation was unavailable in the imported IFC-based model, and room-separation lines did not resolve that limitation.

Pipework and ductwork were represented through modeled length. Smaller fittings and installation components were not quantified as separate planning objects. Their expected production effort is therefore absorbed into the average productivity assumption used for the length-based work package. The resulting values are suited to an early capacity check at the level tested here, while detailed installation estimating would require a richer breakdown of the technical work.

5.3 Setting up the BIM to Excel to Revit workflow

The workflow follows a Revit → Excel → Revit information path. Revit schedules expose the model quantities and planning identifiers. Excel groups the exported information into planning units and performs the takt calculations. Dynamo reads selected CSV output from Excel and writes the corresponding plan information to Revit parameters where a physical model association is available.

Zone ID and Work Package ID provide the two identifiers required by the calculation. Zone ID states where the work belongs in the production structure. Work Package ID states which production scope the quantity represents. Their combination allows several model elements to be summed into one planning unit before the duration is calculated.

The writeback structure uses Takt_ZoneID, Takt_WorkPackageID, Takt_Period, PeriodIndex, Takt_Start, Takt_End, and Plan_VersionTag. Model_VersionTag remains associated with the source quantity data so that the calculation can be traced to a particular model condition. Appendix A.11 shows the corresponding Revit parameter and schedule setup.

Schedules were exported by work type and discipline and transformed in Excel with Power Query. Individual model objects supply the raw scheduled values. The calculation groups these values by zone and work package, so object-level detail remains in the source information while the workload check operates at the planning-unit level.

The workbook is organized around source information, calculation, planning output, and traceability. Raw exports and the assumptions required by the calculations enter the workbook before the grouped Model_All table is produced. Each Model_All row represents one planning unit. The calculation then associates that row with the productivity rate and takt settings required to derive its capacity indicators.

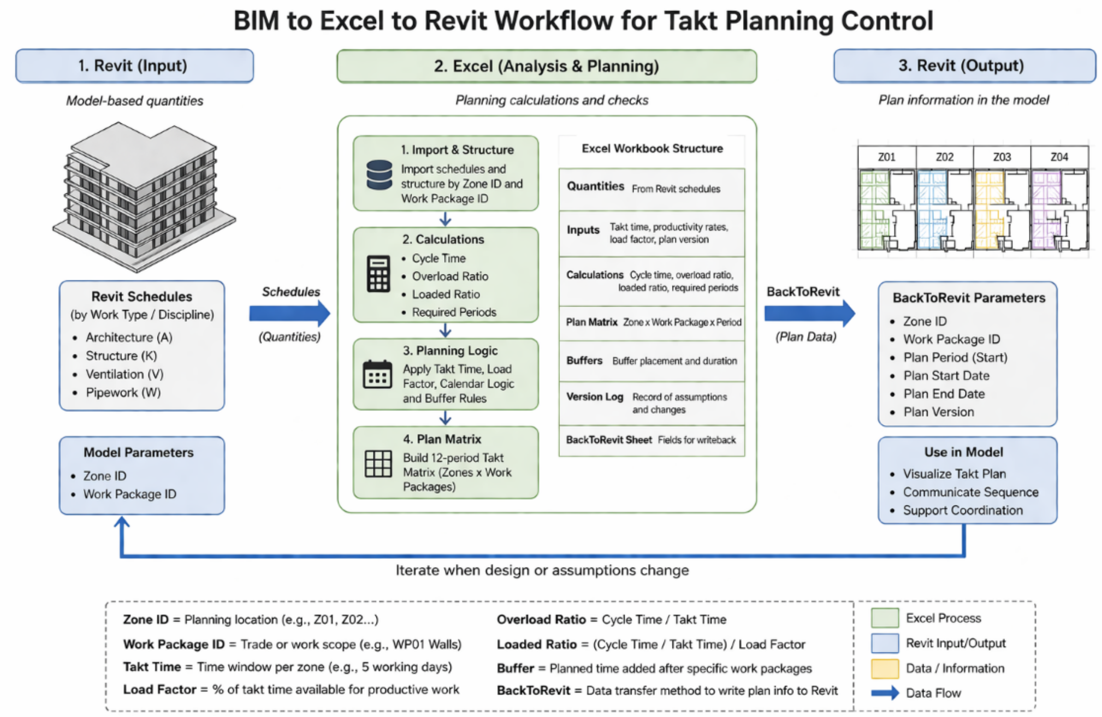

Figure 5.1: BIM to Excel to Revit workflow overview.

The calculation sequence begins by converting quantity into cycle time:

Cycle time = Quantity ÷ Productivity rate

Full takt use is then expressed through:

Overload ratio = Cycle time ÷ Takt time

For the load-adjusted view:

Loaded ratio = Cycle time ÷ (Takt time × LoadFactor)

With the project setting of a five-day takt and a LoadFactor of 0.7, the usable load-adjusted window is 3.5 working days. RequiredPeriods indicates whether the calculated cycle time requires more than one complete takt period.

A WarningThreshold of 0.85 is also stored in the workbook settings. The project-model interpretation uses the actual loaded-ratio pattern when discussing relative capacity pressure. A work package can therefore be described as comparatively capacity-sensitive even when it has not crossed a separate warning setting.

The plan matrix translates the planning units into the 12-period sequence across Z01 to Z04. Each work package moves through the apartment zones one period apart according to the production train defined in Section 5.1. BUFFER occupies a plan period but remains outside the physical writeback.

BackToRevit output is generated from the plan matrix through Power Query. Discipline-specific exports are created where model writeback is relevant. BUFFER has no model element because it represents planned time. WP04 and WP05 also remain

Calculation	Formula or logic	Meaning in the workflow
Cycle time	Quantity ÷ Productivity rate	Estimated number of working days needed for one work package in one zone.
Rounded cycle time	Rounded cycle time value	Makes the calculated duration easier to use in period-based planning.
Overload ratio	Cycle time ÷ Global takt time	Shows whether the calculated duration exceeds the chosen takt time. A value above 1.0 means full overload.
Loaded ratio	Overload ratio ÷ Load factor	Shows capacity sensitivity when only part of the takt window is treated as usable production time.
Overload flag	If overload ratio > 1.0, then overloaded	Identifies whether the planning unit exceeds the takt time under the selected assumptions.
Required periods	Rounded period need based on cycle time and takt time	Shows whether a work package needs more than one takt period.
Action suggestion	Based on overload result	Shows whether the planning unit can be kept or needs review.
BackToRevit	Yes or No	Shows whether the work package should receive plan-period data in Revit.

Table 5.2: Key workbook calculations and meanings.

outside direct physical writeback because their quantities are calculated from interpreted surface information. The available model contains no distinct physical work-package elements to which those calculated painting quantities can be written directly.

Dynamo then reads the CSV information and matches the selected planning fields with the corresponding Revit parameters. The writeback occurs after the Excel calculation and plan matrix have been produced, so model communication remains downstream from the workload check.

5.4 From controlled prototype to project model application

The controlled prototype provided the first demonstration of the complete information path. Its wall work package used an area-based quantity and its pipe work package used length. This allowed export, calculation, matrix generation, and writeback preparation to be tested without the model-interpretation problems introduced by the project data.

The project-model application retained the prototype's grouping and calculation logic while introducing a less controlled information structure. Quantity data now came from architecture, structure, ventilation, and pipework files, and several work packages required rules that interpreted the available model information as production quantities. Zone ID and Work Package ID continued to provide the grouping structure, while quantity-driver suitability became an additional condition for producing a defensible planning signal.

Appendix B contains the controlled prototype outputs, while Appendix A contains the final project-model workbook and writeback structures. Chapter 6 reports the empirical results from both stages.

5.5 Boundaries of the project model application

The project application represents one model condition and one main planning state. The workbook contains model and plan version fields that allow different states to be distinguished, yet the available project material did not contain a sequence of dated model revisions suitable for repeated comparison.

Productivity values are planning assumptions used to translate quantity into expected duration. Methvin production-rate information informed the architectural and finishing assumptions, which were adjusted into crew-based daily values for the project calculation (Methvin, n.d.-a, n.d.-b, n.d.-c, n.d.-d, n.d.-e). MEP Academy (2020) informed the ductwork assumption. Pipework uses a project-level length-based assumption because the available model does not separate the installation effort into fittings and other smaller components.

These productivity values are separate from measured production rates for the anonymized project. A different production-rate assumption changes cycle time and therefore changes both overload and loaded ratios. The project-model results describe the selected assumption set. They are not observations of actual site performance.

Model detail creates another boundary. Wall and ceiling painting require interpreted quantity logic because reliable production surfaces were unavailable directly from rooms or modeled ceiling elements. Technical work uses linear quantities while part of the installation effort remains represented through productivity assumptions. Each calculated ratio therefore inherits the limitations of the quantity driver used to generate its cycle time.

Manual information preparation is also required. Zone and Work Package IDs have to remain consistent across the relevant files before exported quantities can be grouped correctly. Imported or linked IFC elements cannot always be handled in the same way as native Revit elements. The project-model evaluation therefore includes the information-discipline requirement that precedes the calculation.

6

Results

The empirical results are presented in two parts. Sections 6.1–6.7 report the interview material, followed by the controlled prototype and project-model results in Sections 6.8–6.11. Counts in the interview sections describe recurrence within the nine interviews, while the model sections report outputs produced by the artifact.

6.1 Interview material and respondent roles

Nine anonymized respondents contributed interview material based on practical experience of takt planning, takt control, production management, or digital support for takt-based construction. Their experience included repetitive residential work and renovation as well as projects containing more technically complex production areas.

Exact job titles and organization names are withheld to reduce identification risk. Table 6.1 groups the respondents by broader role category. Counts used in the following sections indicate how many respondents described a particular theme in the interview material.

Respondent grouping	Number of respondents	Role in the interview material
Site-management roles	3	Practical follow-up, zone balancing, handovers, site detection, and local adjustment
Project-management roles	2	Planning maturity, technically complex projects, special spaces, and project-level revision logic
Production, procurement, development, or product/process roles	3	Takt development, digital systems, production data, documentation, and organizational implementation
Project-lead and takt-consulting role	1	Multi-project takt planning, client and contractor support, work packaging, subcontractor involvement, and takt control routines

Table 6.1: Interview respondent grouping.

6.2 How zones and work packages were defined in practice

Seven of the nine respondents described zone definition as an iterative planning task. An initial division could begin from repeated spaces in the building, but the zones were then reconsidered when the amount or organization of work made the first division unsuitable. The three site-management respondents described cases where one zone size worked poorly for a particular trade even though the same division was acceptable to another.

Trade preferences made this negotiation visible. One site-management respondent explained that painters may prefer a larger working area because drying affects the organization of their work, while plumbers can prefer a smaller area when service work becomes too dense. Another described a case where a plumber wanted an existing zone divided because it contained too much work, while a carpenter considered the proposed smaller zone inefficient for the carpentry scope.

Technical areas created a different zoning problem. Four respondents emphasized spaces where service density or weaker repetition made the ordinary takt structure difficult to apply. A project-management respondent described special rooms that may need to be identified separately during early planning, while the project-lead and takt-consulting respondent linked MEP-heavy areas to decisions about how production areas are divided.

Five respondents described projects where ordinary repeated areas and special areas received different production treatment. Site-management respondents referred to off-takt areas or separate production recipes. The project-lead and takt-consulting respondent described a hospital where differences between building wings and central technical areas led to several takt trains being used before interior execution began.

Work packages were discussed by four respondents as takt wagons or grouped work operations. The senior production and procurement respondent described beginning with a standard sequence and adapting it to the project before checking the balance of the wagons. Site-management respondents described estimating the work within a zone and grouping compatible activities when they could be carried out without blocking one another.

Across these accounts, zone definition and work-package definition were repeatedly considered together. Respondents adjusted the spatial division when the work inside it created a problem, while work-package balance was judged in relation to the areas through which the wagon would move.

6.3 Information needed before locking the takt plan

All nine respondents discussed the maturity of information available before a takt plan is used for production coordination. Their accounts did not require every design detail to be complete. They described a point where the information affecting the planned work becomes stable enough for the team to rely on the sequence and expected production conditions.

Design information influenced the definition of the work itself. Layout and MEP service areas were mentioned because they affect the amount or arrangement of work within a zone. Production preparation concerned a different problem: subcontractor input and site readiness affected whether the planned duration could be achieved once the work entered production.

Two respondents described a direct tension between early takt planning and later information maturity. A project-management respondent explained that an early plan can be developed from drawings that already show enough of the production structure to begin planning. As the design matures, the plan is updated. The development-management respondent described the same timing issue from another direction: waiting for complete design information gives the planner greater certainty but leaves less opportunity to influence production arrangements before they are fixed.

Three respondents connected the information requirement to takt length. A product or process-development respondent explained that a weekly takt can operate with broader information than a one-day or shorter takt. The residential production respondent described two- to four-hour takt periods where small uncertainties consume a large share of the available time. A senior production and procurement respondent similarly connected short periods with faster detection because site management may have only a few hours to react.

Late customer, tenant, or resident changes appeared in three interviews. The residential production respondent described an enlarged kitchen introduced after the takt plan had been established. The zone boundary remained unchanged, while the amount of work increased and the change affected material planning, procurement, and logistics.

6.4 Sources of takt instability during execution

The interview material contained both changes to planned work content and problems with the conditions needed to carry out that work. Design changes could alter workload or the way work was distributed between zones. Production problems appeared when the planned resources or physical prerequisites were unavailable when the work was expected to begin.

Design change was mentioned by seven respondents. The effect depended partly on when the change occurred. Two respondents described small changes that could be absorbed when they did not affect sequence or material preparation. Larger changes became more disruptive when they affected service areas or required procurement after earlier production decisions had already been made.

Seven respondents mentioned labor or resource instability. Site-management respondents described sickness and crews arriving with fewer workers than planned.

A product or process-development respondent raised variation in worker productivity, noting that experienced and new installers can perform the same work at different speeds. The project-lead and takt-consulting respondent connected labor availability to subcontracting arrangements when workers could be moved between projects.

Material and logistics problems appeared in six interviews. Respondents described situations where the required material was missing at the start of a takt period or arrived in a way that obstructed the production area. The residential production respondent connected this problem particularly closely with short takt, where waiting for material can consume a large part of the available period.

Five respondents described missing prerequisites or physical site conditions. The senior production and procurement respondent used concrete moisture as an example because flooring cannot proceed until the substrate condition is acceptable. The residential production respondent similarly described drying problems that could lead to an area being skipped and returned to later.

Uneven workload was mentioned by six respondents. Site-management respondents described the imbalance through differences in expected work hours, while the senior production and procurement respondent connected it to wagon loading. The product or process-development respondent pointed out that the same planning error becomes harder to absorb as the takt period becomes shorter.

6.5 Detecting takt problems during execution

All nine respondents described routines or signals used to detect production problems before a larger plan change became necessary. The common feature was frequent comparison between the planned handover and what was actually happening in the production area.

Site-management respondents described daily and weekly routines in detail. One used daily huddles to raise current problems and weekly meetings to concentrate on unresolved work. Another described a Wednesday check during a weekly takt so the team could estimate whether the Monday handover would be achieved. A third emphasized that finding an unfinished zone only at the Monday handover meant that the opportunity for earlier recovery had already been lost.

Direct production behavior also acted as a warning. The development-management respondent described the phrase “trying to keep up” as a signal that the contractor was already recovering from lost rhythm. The product or process-development respondent discussed incomplete work packages that create re-entrant flow when a trade has to return after later production has already moved through the area.

Digital follow-up appeared in five interviews. The senior production and procurement respondent described workers recording progress in a mobile application and attaching photographs of obstacles. Another respondent described lead workers updating digital checklists near the work area. The residential production respondent described workers marking the start and completion of work in a location, giving management a more immediate view of wagon status.

Use of digital systems still depended on site behavior. One respondent had experienced weak early adoption of a mobile application before training and interface changes improved its use. Another emphasized that a digital representation is useful only when the production schedule remains current enough for workers and supervisors to rely on it.

6.6 Response to overload and delay

Respondents generally described attempts to preserve the existing takt structure before changing the broader plan. The first actions were usually local to the affected work or location, while changes to zone structure or takt duration appeared later in the accounts.

Overtime or weekend work was mentioned by six respondents. The residential production respondent described overtime as an early recovery action and additional labor when the delay could not be absorbed through time alone. Two site-management respondents described weekends as recovery opportunities within a weekly takt.

Resource adjustment was mentioned by seven respondents. The senior production and procurement respondent described wagon and resource balancing through recurring takt meetings. A development-management respondent pointed out that the available response can depend on subcontractor capacity and contractual conditions. The product or process-development respondent described a multi-skilled worker outside the takt train as a possible resource buffer for smaller disturbances.

Seven respondents discussed buffer use or temporarily bypassing an affected area. Site-management respondents described spare areas and empty wagons used to keep other work moving. The project-lead and takt-consulting respondent described leaving a design-blocked takt area and returning after the design issue was resolved.

Changes to takt zones or takt time were described by four respondents as later interventions. A site-management respondent associated zone changes with problems too large for a minor local adjustment. The project-lead and takt-consulting respondent explained that changing takt time during production can confuse workers who are already following the existing rhythm. Other respondents similarly described structural plan changes after time, labor, or local sequencing had proved insufficient.

A recurring response pattern appears across the interviews. Local recovery measures often came before broader changes to the takt structure. Respondents described using available time, resources, buffers, or temporary bypass of an affected area, while changes to zone structure or takt duration appeared when the disturbance could no longer be contained within the existing production arrangement.

6.7 Documentation and digital support for takt control

Seven respondents described some form of documentation or digital evidence trail. A site-management respondent gave a distinction between small issues that may be recorded temporarily on a whiteboard and larger issues that remain in meeting minutes or digital systems. Other respondents described recurring site records connected to huddles and weekly production meetings.

The development-management respondent described documentation through immediate production control, contractual evidence, and later learning. The same respondent observed that documentation can weaken when site teams are busy, creating a practical reason for keeping the recording process simple. The product or process-development respondent described software logs that preserve status changes and identify who changed the plan.

Four respondents discussed BIM or structured quantity information as a possible support for planning. The development-management respondent connected this to design change because repeated manual quantity extraction becomes burdensome when updates occur frequently. A project-management respondent described BIM use for quantity extraction and schedule visualization. The residential production respondent had experience with some BIM-derived quantity calculations but described no direct takt-plan connection to the model.

Model detail appeared as a recurring limitation in these accounts. The residential production respondent explained that a model can contain a large element such as a pipe while leaving hangers, screws, and other installation content unmodeled. The product or process-development respondent also questioned detailed BIM-based production control when model information lacks the level of detail or project status required by site work.

Respondents connected digital support with information that remained current enough to correspond with the decisions being made on site. Quantity data was described as a possible input to planning and updating, while detailed execution control continued to depend on current production information and practical follow-up.

6.8 Controlled model test of the BIM to Excel to Revit loop

The controlled model test used walls and pipes to represent two different quantity drivers before the workflow was applied to the project model. Walls supplied an area-based input and pipes supplied a length-based input. Appendix B.1 and Appendix B.2 contain the prototype quantities and calculation assumptions.

Revit schedule quantities were successfully transferred into the Excel calculation. One wall planning unit exceeded the complete takt period under the prototype assumptions. The pipe planning unit remained within one takt period, while its loaded ratio expressed the share of selected load-adjusted capacity occupied by its calculated cycle time. The prototype therefore provided both conditions required to examine full-takt overload and load-adjusted capacity use as separate calculation outputs.

The plan matrix was also transformed into a BackToRevit export containing the selected planning identifiers and timing information. Appendix B.3 shows the prototype calculation, while Appendices B.4 and B.5 show the plan matrix and writeback output. The controlled stage established that the complete information path could operate before the project-model structure was introduced.

6.9 Project model application and capacity-sensitive work packages

The project-model application used one apartment floor from the anonymized IFC-based residential model and was independent of the organizations represented in the interviews. Four apartment zones were combined with the eight work packages defined in Chapter 5.

The zones differed in both area and work-package quantity. Z01 contained 79 m^2 of apartment area and Z04 contained 58 m^2, yet apartment size alone did not determine which planning units occupied the largest share of takt capacity. The quantity relevant to each work package and its productivity assumption determined the calculated duration.

Every planning unit had RequiredPeriods = 1 under the final crew-based productivity assumptions. None of the project-model units required more than one full takt period. Loaded ratios still varied across work packages and zones, showing different shares of the load-adjusted capacity under the selected quantity, productivity, and takt assumptions.

Work package	Z01	Z02	Z03	Z04
WP01 Interior partitions	0.63	0.73	0.36	0.76
WP02 Door sets	0.30	0.36	0.12	0.12
WP03 Floor finishes	0.50	0.54	0.39	0.37
WP04 Wall painting	0.50	0.71	0.58	0.63
WP05 Ceiling painting	0.71	0.66	0.54	0.52
WP06 Suspended ceilings	0.05	0.16	0.09	0.09
WP07 Pipework	0.67	0.69	0.63	0.56
WP08 Ventilation ducts	0.66	0.66	0.50	0.43

Values above 1.0 would indicate full overload. In the final project application, no work package exceeded the full overload threshold, but several work packages showed higher loaded ratios and were therefore treated as watch packages.

Table 6.2: Loaded ratio by zone and work package. Loaded ratio expresses the share of the selected load-adjusted capacity occupied by the calculated cycle time. None of the project-model planning units exceeded the complete takt period under the final assumptions. The loaded-ratio values are interpreted comparatively across work packages and zones.

Table 6.2 reports the loaded ratio for each zone and work-package combination. A loaded ratio above 1.0 means that the calculated cycle time exceeds the selected load-adjusted capacity. None of the project-model planning units exceeded the complete takt period when evaluated with the overload ratio. The loaded-ratio values are interpreted comparatively in Section 7.4.

Interior partitions showed loaded ratios of 0.63 in Z01, 0.73 in Z02, 0.36 in Z03, and 0.76 in Z04. These values came from the wall quantity assigned to each zone together with the WP01 productivity assumption and the common takt settings.

Pipework also used a relatively large share of load-adjusted capacity across the four zones, with values from 0.56 to 0.69. Ventilation ranged from 0.43 to 0.66. Both technical work packages could therefore be evaluated through the same time-based calculation despite using quantities from separate discipline files.

Wall painting ranged from 0.50 to 0.71 across the four zones, while ceiling painting ranged from 0.52 to 0.71. WP05 Ceiling painting reached 0.71 in Z01 and 0.66 in Z02, placing several of its loaded-ratio values within the same numerical range as the other work packages with comparatively high capacity use.

6.10 Takt matrix and writeback structure

The project-model planning units were arranged into a 12-period takt matrix using the production sequence defined in Section 5.1. Work begins in Z01, with the same work package moving through Z02, Z03, and Z04 one period apart. Table 6.3 presents the resulting matrix, while Appendix A.7 contains the corresponding Excel output.

Takt_ZoneID	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12
Z01	WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02			
Z02		WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02		
Z03			WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02	
Z04				WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02

The matrix shows how the work packages move through the four zones one period apart, with a planned buffer after painting.

Table 6.3: Final 12-period takt matrix.

BUFFER appears after the painting work and before floor finishes and doors. It remains visible in the matrix as planned time without being written to a physical Revit element.

Capacity and calendar time are treated separately. The overload calculations use the five-working-day production period. BackToRevit dates advance through seven-day calendar intervals. The resulting model communication can therefore show actual calendar dates while the capacity calculation remains based on working time.

6.11 Evidence boundaries in the project model

The project result reflects the information available in the selected IFC-based model. Architecture, structure, ventilation, and W files supplied the quantities used by the workflow. Electrical work remained outside the calculation because the provided files contained no usable electrical model, while the KP files fell outside the selected interior work-package structure.

Several quantities required interpretation before they represented the intended production scope. Reliable rooms could not be generated from the imported model, even after room-separation lines were tested. Wall painting therefore used wall length with paint height and side factors, while ceiling painting used apartment-zone area. Suspended ceilings remained tied to the modeled ceiling elements.

Technical work was represented through pipe and duct length. Smaller installation content was not modeled as a separate quantity driver and was represented through the productivity assumptions used for the length-based packages. The resulting ratios therefore describe an early workload check at the selected level of technical detail.

The project-model calculation was tested with a weekly takt and the quantity and crew assumptions prepared for that time scale. Two-hour, four-hour, and one-day takt structures were outside the project-model test.

Only one model condition and one main planning state were available. Model and plan version fields could be populated and traced within that condition, yet no empirical sequence existed for observing how a changed model quantity altered the overload calculation from one dated state to another.

Manual preparation remained part of the final workflow. Zone and Work Package IDs had to be assigned consistently across the relevant discipline data before grouping was possible. Imported IFC elements also limited how directly information could be associated with native Revit objects. The project-model result therefore depends on the quality of the coding and quantity interpretation that precede the calculation. assumptions.

7
Analysis

BIM-derived quantity becomes relevant to takt control only after the quantity is expressed through the same production unit and time logic as the plan. The interview and model results make it possible to examine that translation from several sides: how zones and work packages are defined, what information the calculation can represent, and where production conditions remain outside its reach.

7.1 Why zone and work package became the planning unit

The project model uses the combination of zone and work package because takt production connects the movement of a trade with a physical location. Location-based planning establishes the spatial part of this relationship, while equal takt duration adds the time constraint under which work has to move through those spaces (Kenley & Seppänen, 2010; Seppänen, 2014).

Interview evidence reinforces the need to retain both dimensions. Seven respondents described zone definition as iterative, and the site-management examples showed why physical size alone can produce a poor production division. A plumber can experience excessive work inside a zone that another trade considers too small to divide. The same boundary therefore carries a different workload depending on the work package moving through it.

Tommelein's (2017) work-density concept provides a theoretical explanation for this result because it connects the time required by a trade with the work performed within a location. The project model contains a related pattern: apartment areas differ, yet the loaded-ratio ranking does not follow apartment area directly. The relevant work-package quantity and productivity assumption determine the calculated duration, so apartment geometry alone cannot describe the capacity pressure within a zone.

Work Package ID performs this production-scope function within the artifact. Isaac et al. (2017) show that BIM objects can be grouped into construction work packages, providing a basis for turning object-based information into a production-oriented scope. Zone ID then places that scope in the location where the takt plan expects the handoff to occur.

The combined unit also prevents two forms of aggregation from hiding pressure. A whole-trade quantity can conceal the zone in which work is concentrated. A whole-zone total mixes production scopes that have different quantity units and productivity rates. One work package in one zone retains the information required to convert a specific amount of work into a duration at the location where the duration matters.

7.2 Information maturity as a condition for takt reliability

All nine respondents discussed a level of information maturity before the takt plan could be relied on for production coordination. Their accounts did not equate maturity with a completed design. The relevant point was whether uncertainty still affected the production structure strongly enough to change the work package, its zone, or the conditions under which it was expected to be performed.

Seppänen's (2014) equal-duration requirement depends on a sufficiently stable understanding of what each work package contains when the takt period is assigned. The enlarged-kitchen case gives a practical example of this condition. The zone boundary remained unchanged after the plan had been established, while the amount of work and its material implications increased. The planning unit kept the same spatial identity even though its production content had changed, which can alter the duration represented by the earlier plan.

Production readiness introduces a separate form of information maturity. Ballard and Howell (1998) connect reliable assignments with whether work is sound and ready for execution, while Hamzeh (2009) places constraint removal before committed short-term work. The interview examples of concrete moisture and missing material correspond with this problem because the planned quantity may remain unchanged while the work cannot begin.

The BIM to Excel calculation directly addresses modeled work content. When a quantity changes, the workflow can recalculate cycle time and compare the resulting duration with takt capacity. Material arrival and handover completion are separate information conditions; a low overload ratio provides no evidence that either prerequisite has been satisfied. Those conditions require current information from production follow-up.

The quantity calculation depends on model and planning information being mature enough to represent the intended work. The artifact addresses this planning-stage condition by recalculating modeled work content against takt capacity. Execution still depends on current site information confirming that the conditions for performing the work are present when its takt period begins. The two forms of information therefore remain connected to different parts of takt control.

7.3 Reading overload ratio as a planning signal

The overload ratio converts a modeled quantity into a time-based planning signal. Quantity is first divided by the productivity rate to obtain cycle time. Dividing that duration by takt time then shows whether the calculated production duration exceeds the selected period.

This sequence changes the meaning of the original quantity. A value in square metres, metres, or units has no common workload scale across the eight work packages. Once each quantity is translated through its relevant productivity assumption, the resulting duration can be compared with the same takt period. The planning signal therefore depends as much on the assumed rate as on the physical quantity.

Riekki et al. (2024) also use detailed quantitative indicators to locate pressure within takt production, but their empirical indicators are based on actual production progress. The project workflow operates earlier. Its ratio represents expected capacity use before execution, so it cannot be interpreted as evidence that production has already deviated from the plan.

The controlled prototype establishes the difference between full takt overload and load-adjusted capacity use below that condition. One wall planning unit exceeded the complete takt period, while the pipe planning unit remained within it. The pipe result could still be expressed through the share of the smaller load-adjusted window occupied by its calculated cycle time. The two cases therefore show how overload ratio and loaded ratio describe different relationships between cycle time and the selected takt settings.

The project model did not produce a full overload under the final assumptions. RequiredPeriods remained equal to one for every planning unit. The variation therefore moved to the loaded ratio, which compares cycle time with the smaller load-adjusted capacity selected by the workbook.

The 0.7 LoadFactor is an artifact assumption used to reserve part of the five-day period from the load-adjusted calculation. It is not a value prescribed by the cited takt literature. Within this study, the factor exposes how much of the chosen load-adjusted window is occupied before the complete five-day takt is exceeded.

Neither ratio identifies the cause of a future production problem. A high calculated value can arise because the modeled quantity is large for the work package or because the productivity assumption translates that quantity into a long duration. The actual production outcome can then be affected by site conditions that are absent from the calculation. The ratios therefore locate calculated capacity pressure without diagnosing every condition that may later create delay.

7.4 Capacity-sensitive work packages in the project model

The project-model loaded ratios form a continuous range across the work packages and zones. Every planning unit fits within one complete takt period, while the share of selected load-adjusted capacity occupied by each unit differs. Capacity sensitivity is used here as a comparative description of that capacity use under the selected assumptions; it is not a separate pass/fail classification.

Interior partitions illustrate the difference between numerical pressure and production-sequence consequence. WP01 reaches 0.76 in Z04 and 0.73 in Z02 because the wall quantities in those zones, combined with the WP01 productivity rate, produce relatively long cycle times. Its early position in the sequence has no effect on that calculation. Sequence becomes relevant after the ratio has been calculated because a delayed partition handover can affect later ceiling and finishing work.

Quantity-heavy and capacity-sensitive describe different properties of a work package. Quantity-heavy refers to the amount of the selected physical quantity, while capacity sensitivity appears after that quantity has been converted into time through productivity and compared with takt capacity. A larger physical quantity can still produce a lower loaded ratio when its productivity rate is high enough, while a smaller quantity can occupy more capacity when its corresponding rate is lower.

The distinction is especially relevant across different work packages because their raw quantities use different units. Metres of duct, square metres of partitions, and counts of doors cannot be ranked as workload from their numerical quantity alone. Cycle time creates the common time dimension needed before their use of takt capacity can be compared.

Wall painting demonstrates how model interpretation enters that conversion. The quantity combines paint-relevant wall information from the architecture and structure files and uses wall length, paint height, and side factor to derive the work-package quantity. Monteiro and Poças Martins (2013) explain why BIM quantity output depends on modeling and extraction rules; the WP04 result inherits the assumptions used to construct that quantity.

Ceiling painting reaches loaded ratios of 0.71 in Z01 and 0.66 in Z02, values comparable with several of the work packages identified as having relatively high capacity use. Its quantity driver is apartment-zone area because the modeled ceiling elements do not cover the full painted surface. The resulting ratio reflects both that area-based quantity rule and the productivity assumption used to translate the quantity into time.

Pipework and ventilation show a different boundary. Both can be converted through length-based productivity assumptions and compared with the architectural work through the common time scale. Their loaded ratios still represent technical installation through a simplified driver because smaller components are absorbed into average productivity. The interview evidence on MEP-heavy areas gives practical context for why technical workload can disturb repetition even when the model provides only part of the production detail.

The loaded-ratio pattern identifies planning units whose calculated cycle times occupy larger shares of the selected load-adjusted capacity. Each value has to be interpreted through the productivity rate and quantity driver that produced it, since changing either input can alter the calculated pressure without changing the work-package identity.

7.5 Why calculation still requires planning judgment

Interview respondents described several responses to overload or delay, and their accounts show why a numerical signal cannot determine the production response by itself. Added time, resource adjustment, and use of available buffers appeared frequently, while zone or takt-time changes were generally described later when local handling was insufficient.

Binninger, Dlouhy, Steuer, and Haghsheno (2017) similarly treat takt adjustment as a response to the condition affecting the production system. The calculation can narrow the discussion by locating a planning unit where expected duration occupies a large share of the selected load-adjusted capacity. It provides no direct evidence about whether the appropriate response concerns labor, sequence, zone structure, or the assumption used in the calculation.

Patterns across zones can change how the calculated pressure is interpreted. A high value in one location can originate in a locally concentrated quantity. Repeatedly high values for the same work package can point to a condition that follows the work package across the zone structure, such as its productivity assumption or the way its scope has been defined. These patterns describe where pressure is concentrated and whether it recurs across locations. They do not determine which production response is appropriate.

Riekki et al. (2024) identify detailed outliers from actual production-progress information. The project workflow uses similar location and work-package specificity at the planning stage to identify expected capacity pressure before execution. The two forms of information answer different questions: Riekki et al.'s indicators locate where actual production is diverging, while the BIM-derived calculation locates where modeled workload occupies a larger share of assumed capacity.

Revision support has the same limitation. The workbook can preserve which quantity, assumption set, and plan version produced a pressure point. That information can enter a revision discussion, but the study did not evaluate whether a particular revision decision improved production. Practitioner judgment remains necessary because the causes described in the interviews often extend beyond the information contained in the model.

7.6 How model structure shaped the quantity results

Every calculated ratio depends on a quantity that has already been interpreted as representative of a work package. Monteiro and Poças Martins (2013) show that BIM quantity takeoff depends on model authoring and extraction rules. The project application makes that dependence visible because the selected work packages could not all be constructed from the model in the same way.

Zone ID and Work Package ID solve the grouping problem only after the underlying quantity has been selected. Ljung et al. (2023) and Viklund Tallgren et al. (2022) emphasize compatible information structures between BIM and takt planning. The project workflow applies this principle to grouping, while quantity-driver suitability remains an additional requirement for the duration calculation.

Some work packages align closely with modeled elements. Door sets can be represented through counts, and linear MEP objects provide measurable lengths. Painting shows a weaker direct alignment between model object and production scope because the intended painted surface had to be derived from other model information.

The interview material describes a similar production-information boundary. Respondents saw potential in BIM-supported quantity use while also pointing to installation content that may be absent from the model. The example of pipes without hangers or screws is particularly close to the project-model MEP calculation, where linear quantities are available but smaller installation components remain implicit in productivity.

The division between Revit and Excel follows from this difference between model information and planning interpretation. Revit retains the objects and scheduled quantities, while Excel makes the chosen transformations and production assumptions visible. A mathematically correct formula can still produce a weak planning signal when the input quantity represents the work poorly, so calculation transparency cannot compensate for an unsuitable quantity driver.

7.7 Traceability through versioning, logs, and writeback

Traceability in the artifact begins by keeping the source model condition separate from the planning state. Model_VersionTag identifies the model information from which quantities were derived, while Plan_VersionTag identifies the planning output associated with those quantities and assumptions. The Version Log provides a place for later planning changes to be recorded.

Juszczyk et al. (2016) establish why changing BIM states require identification and analysis. For the takt workflow, the consequence of a design update depends on what part of the planning unit changes. A revised wall layout can alter a quantity; a changed zone boundary can reassign existing quantity to another planning unit; a sequence change can alter timing while leaving the modeled quantity untouched.

BackToRevit provides selected planning information after the Excel calculation. Takt_ZoneID and Takt_WorkPackageID retain the planning identity, while Takt_Period and PeriodIndex communicate the planned order. Takt_Start and Takt_End add calendar information, and Plan_VersionTag identifies the planning state associated with those fields.

Planning elements that lack a direct physical model object remain separated from this writeback. BUFFER exists only in the plan. WP04 and WP05 use calculated surface quantities that are not represented as distinct physical work-package elements in the available model. Keeping these conditions separate prevents the writeback structure from implying a physical model association that the project data does not contain.

The evidence stops at traceability for one model and plan condition. The prepared fields can distinguish later information states, while the available project material supplies no complete revision history through which repeated comparison could be observed. The study demonstrates an information structure prepared for revision traceability. Its performance across repeated real revisions remains unevaluated.

7.8 Interpreting the workflow under defined assumptions

The project-model result belongs to a deliberately bounded test. One apartment floor provides enough variation to examine the zone and work-package logic while keeping the model preparation and quantity interpretation visible. It does not establish how the same implementation behaves across an entire building or several simultaneous takt trains.

One model condition creates a similar boundary around revision interpretation. The workflow can calculate capacity use for the available state and associate that result with a model and plan version. The available data cannot show how the ratios actually changed from one real design issue to the next.

Model structure affects interpretation before productivity is considered. Missing room functionality changed the route through which painting quantities were obtained, while length-based technical quantities placed more production content inside the productivity assumptions. A loaded ratio therefore represents the combination of model information and the rule selected to turn that information into a work-package quantity.

Productivity then acts directly on the calculated duration. A higher assumed rate shortens cycle time for unchanged quantity, while a lower rate lengthens it. The source and level of the productivity assumption therefore affect which planning units appear to use more capacity. Rates derived from contractor experience or measured local production would represent a different assumption basis from generic external production-rate information.

The final project-model result has to be read within this chain. Every planning unit fits one takt period under the selected quantities, productivity assumptions, takt time, and load factor. Changing one of these inputs can alter the calculated pressure without any change to the underlying geometry.

Interview evidence adds the final boundary. Respondents described site conditions that can disrupt takt even when the amount of modeled work remains unchanged. The artifact therefore gives its most defensible information where the planning question can be expressed through a modeled quantity and the assumptions required to convert that quantity into time.

7.9 What BIM-based quantity checks add to takt planning control and revision support

The combined evidence places the contribution of BIM-derived quantity checks before production-stage deviation control. The artifact translates model information into the same zone and work-package unit used by the takt plan and then converts different physical quantity types into a common time-capacity relationship.

Work Density research already provides a time-based relationship between work quantity, production rate, and location for workload leveling and takt planning (Singh et al., 2020; Tommelein, 2022; Singh & Tommelein, 2023). The project workflow begins from a related information problem where the quantities originate in BIM discipline files and have to retain a production-oriented zone and work-package identity before the capacity calculation is made. Quantity-takeoff and BIM-takt research explain why model structure, extraction rules, and compatible identifiers affect that translation (Monteiro & Poças Martins, 2013; Ljung et al., 2023; Viklund Tallgren et al., 2022). The resulting contribution lies in carrying BIM-derived quantity through that production structure into a visible capacity calculation while preserving the information state from which the planning output was produced.

The controlled prototype demonstrates that the calculation can distinguish a planning unit whose cycle time exceeds the complete takt period from one that remains within it. The project model shows how loaded ratio behaves when quantity drivers and model interpretation differ between work packages. Loaded ratio expresses the share of the selected load-adjusted capacity occupied by the calculated cycle time. It does not represent actual production deviation because execution data does not enter the calculation.

Traceability extends this planning information toward revision support. Model and plan version fields can preserve which information state produced a particular calculation and takt matrix. The evidence supports a structure for later comparison and planning discussion. Whether the workflow improves decisions made during repeated revisions was not evaluated because repeated real revision states were unavailable.

8
Discussion

Every project-model planning unit fit within one takt period under the final assumptions, but that result was produced through several prior information choices. Model objects first had to be associated with production zones and work packages. Their quantities then had to represent the intended production scope before a productivity assumption could translate them into time. The resulting capacity signal depends on the relationship between model structure, planning structure, and the assumptions used to connect the two.

Work Density research provides a directly related calculation logic for the artifact. Singh et al. (2020) combine quantity take-offs with trade production rates to calculate spatial work density and use that information to study zoning and whether a desired takt can be met. Tommelein (2022) formalizes this relationship through the Work Density Method, and Singh and Tommelein (2023) develop its computational support further. The BIM to Excel to Revit artifact develops the BIM-information side of this relationship by obtaining the selected quantities from model schedules, grouping them through Zone ID and Work Package ID, and retaining explicit links to model and plan state. The contribution lies at the intersection between established workload calculations and BIM-supported takt information structures. The project-model application also exposes what happens when the available model does not provide every production quantity directly.

8.1 From BIM quantities to takt control information

The project model supports the literature requirement for compatible BIM and production structures while showing that compatible identifiers solve only part of the problem. Ljung et al. (2023) and Viklund Tallgren et al. (2022) establish the need for structured links between BIM information and takt planning. Zone ID and Work Package ID provide that link in the artifact, but they do not make the quantity itself representative of production effort.

The painting work packages expose a second requirement beyond compatible identifiers. Both can be assigned to the correct zone and work package, yet their quantities still depend on how the available model represents the intended production scope. Wall painting requires a calculated surface from wall information, while ceiling painting uses apartment area because the modeled ceiling objects cover only part of the intended work. Coding determines which planning unit receives the quantity; the quantity-driver rule determines what production content enters its capacity calculation.

Location and work-package identity are both required for the capacity result to retain its production meaning. Kenley and Seppänen (2010) establish the role of location in production control, while Isaac et al. (2017) show how model data can be organized into construction work packages. Their combination allows calculated pressure to be attributed to a particular scope in a particular place. Removing either dimension prevents the result from identifying the takt handoff to which the workload belongs.

Z01, Z02, Z03, and Z04 follow comparable apartment logic, yet their loaded-ratio patterns vary by work package. Repeated apartment geometry therefore provides only part of the information needed to describe production balance. The quantity assigned to each work package and the productivity assumption used to convert that quantity into time determine the calculated capacity use within each zone.

BackToRevit sits downstream from the capacity calculation. Returning a period or date to the model communicates the planning state but provides no evidence by itself that the assigned workload is feasible. The workload signal is created when quantity and productivity are compared with takt capacity. Writeback then carries selected planning information from that calculation into the model.

8.2 The limits of workload visibility

The controlled prototype and project-model application produce two different forms of evidence. The prototype contains a planning unit whose expected duration exceeds the complete takt period. The project model contains no full overload under the final assumptions; its variation lies in the share of the selected load-adjusted capacity occupied by the calculated cycle time of each planning unit.

Loaded ratio makes this second condition visible by comparing cycle time with the load-adjusted takt window. The LoadFactor of 0.7 is a chosen workbook assumption, meaning that the project interpretation reserves part of the five-day takt from the load-adjusted capacity calculation. A loaded ratio therefore says how the selected assumption set uses that chosen capacity; it does not establish a universal boundary between acceptable and unacceptable takt loading.

The distinction becomes especially relevant when different work packages are compared. Raw quantities remain physically incompatible: a square-metre value for partitions and a metre value for pipework represent different production processes and cannot be ranked directly as workload. Productivity converts each selected quantity into expected time, creating the common basis required to compare their use of the same takt period.

A quantity-heavy work package can still occupy a modest share of takt capacity when its assumed production rate is high. A smaller physical quantity can create greater capacity pressure when the corresponding production rate is lower. Capacity sensitivity consequently belongs to the relationship between quantity and productivity, not to the raw quantity by itself.

The project results do not support a rigid class containing only four capacity-sensitive work packages. WP01 reaches some of the highest loaded ratios, and the technical packages also use relatively large shares of the load-adjusted capacity across several zones. WP05 Ceiling painting reaches 0.71 and 0.66 in two zones, placing it within the same numerical range as WP04 and several of the other highlighted cases. The loaded-ratio results form a distribution of load-adjusted capacity use across the planning units, with several packages reaching comparable levels under the selected assumptions.

Productivity assumptions can change that distribution substantially. Since cycle time is calculated as Q/P, reducing productivity P by 20% gives:

$$Q\ /\ (0.8P) = 1.25 \times Q/P$$

For unchanged quantity, calculated cycle time increases by 25%. Loaded ratio increases by the same proportion when takt time and load factor remain unchanged. The example is a mathematical sensitivity test and does not represent an observed project change. It shows how a planning unit can move closer to the selected capacity limit through a change in the productivity assumption even when its modeled quantity stays unchanged.

The interview material also shows that production rate cannot be treated as constant across crews. A product or process-development respondent described differences in productivity between experienced and new installers, while other respondents connected the achievability of planned durations and recovery options with subcontractor input or capacity. External production-rate sources provide a consistent assumption basis for testing the artifact. Historical or measured production from the project itself would have a closer connection to the crews and conditions represented by the plan. The anonymized case contains no such measured production data through which the selected rates could be validated.

Quantity visibility also stops before production readiness. A planning unit can have a low calculated ratio and still fail to start because the material is missing or the preceding work is incomplete. Ballard and Howell (1998) and Hamzeh (2009) provide the theoretical basis for this separation through production readiness and constraint removal. The artifact therefore adds one form of visibility to takt planning while leaving the execution conditions to site-control processes.

8.3 Practical implications for contractors and planners

For a contractor, the workflow identifies the planning unit and assumptions behind calculated capacity pressure before the takt matrix is used as a coordination basis. A general impression that one apartment contains “a lot of work” does not identify whether the calculated pressure comes from the quantity or its conversion into expected time. A loaded ratio tied to one zone and work package exposes the quantity and productivity assumption that produced the result.

This planning-unit signal fits the response pattern described by the interviewees without determining the response itself. Respondents often described attempts to preserve the existing rhythm through local recovery before changing the takt structure. If a high loaded ratio is identified before production, the same planning unit can become the starting point for asking whether its quantity or productivity assumption is credible. Once production begins, the actual response may still depend on labor availability or another condition that the workbook cannot observe.

The interview hierarchy also suggests how the workflow could interact with later follow-up. A quantity-driven change can be recalculated before the project team decides whether the existing plan can absorb it. If a buffer is then used or the sequence is changed, the planning state changes while the model quantity may remain unchanged. Keeping model state and plan state separate preserves whether the changed information originated in the modeled work content or in the planning response.

Excel has a particular role in this research implementation because the source quantity, productivity assumption, and takt settings remain visible beside the resulting calculation. During development and evaluation, the formulas allowed the information path to be inspected from exported quantity through duration and capacity use to the takt matrix without relying on a hidden automated transformation.

The same choice creates a likely scaling challenge. A larger project would create more planning-unit rows and more discipline interfaces, while repeated revisions would increase the amount of versioned information passing through the workbook. Manual coding errors and uncontrolled workbook changes therefore become more consequential as the implementation grows. The thesis does not test the scale at which this becomes impractical, but the single-floor case already shows the dependencies that would have to be controlled.

BackToRevit introduces another practical boundary. Writing period and date information to the model places the planning state beside the physical objects and can support communication of the selected plan. The visual result can still appear more certain than the underlying duration calculation warrants when productivity or quantity assumptions remain uncertain. Retaining the traceable calculation behind the writeback keeps the communicated plan connected to the assumptions from which it was produced.

Consistent coding also requires organizational agreement. The interviews show that zones and work packages are defined through production decisions and trade requirements as well as geometry. A Zone ID records an agreed production boundary; it cannot resolve disagreement between trades about where that boundary belongs. The digital structure depends on those production definitions being established before the identifiers are applied.

8.4 Sustainability perspective

No environmental, economic, or social sustainability outcome was measured in the artifact evaluation. The discussion can consequently identify possible pathways between improved planning information and sustainability outcomes, but those effects remain untested in the project-model application.

From a resource perspective, earlier visibility of workload pressure could reduce situations where a production problem is discovered only after work has already moved through the area. Avoided return visits or rework could reduce unnecessary resource use, but the thesis contains no measurement of waste, transport, material consumption, or carbon emissions through which that effect can be quantified.

Economic implications are similarly indirect. A more specific workload discussion may allow planning time to focus on the zone and work package producing the concern. Whether that saves project time or cost depends on the decision taken and its effect on production. Neither cost savings nor schedule improvement were evaluated in the project-model application.

The social connection is closest to the organization of daily work. Interview respondents described unfinished work, missing prerequisites, and efforts to recover lost takt rhythm. Earlier identification of a tight capacity assumption could give the project team an opportunity to examine that assumption before execution. The thesis does not measure worker stress or working conditions, so no empirical social outcome can be attributed to the workflow.

Demonstrating an environmental, economic, or social sustainability effect would require outcome data beyond the workload calculations collected in this study.

8.5 Boundaries of the method and evidence

The empirical project application is deliberately small. One apartment floor makes it possible to inspect the planning-unit calculation closely, but the numerical loaded ratios belong to that floor, its quantities, and its assumption set. They cannot be generalized as expected ratios for residential construction.

Transferability is more plausible at the level of information logic. Another project can in principle group quantity by production location and work package and convert that quantity into time when suitable model data and productivity information are available. The difficulty lies in whether the required structure can be maintained as the project becomes larger.

Scale introduces several mechanisms that were limited in the case study. More zones increase the number of planning-unit combinations. Additional disciplines create more interfaces where coding and quantity definitions have to agree. A larger model can also contain several production areas with different repetition and technical conditions, matching the interview example where a hospital required multiple takt trains. The same workbook concept could therefore face both data-volume growth and a less uniform production structure.

Shorter takt periods create a different transferability problem. Three respondents linked short takt to a need for more detailed information, and the residential-production example reached two- to four-hour periods. The project workflow was tested with a weekly capacity basis. Applying the same logic to a much shorter takt would require quantity and productivity information at a resolution that can meaningfully represent work over those shorter intervals.

Frequent design revisions create another untested condition. The current fields can separate Model_VersionTag from Plan_VersionTag, which is necessary because design and planning states do not move together. A model update may change quantity without changing sequence. A planner may resequence the work while using the same model. A changed zone boundary can redistribute existing quantity between planning units even if the total modeled quantity remains unchanged.

During repeated revisions, a new model state could be exported and recalculated against the assumption set used for that state. Changed quantities could then be compared with the previous planning units. If the calculated change leads to a planning response, a new Plan_VersionTag could record that planning state separately from the model revision. This sequence describes how the prepared fields could be used; the project material did not contain repeated revision states through which the process could be observed.

Frequent revision increases the amount of manual information that has to remain controlled. New or changed elements require the correct production identifiers, altered zone boundaries can require quantities to be reassigned, and each additional state adds version information that has to remain traceable. The single-state case demonstrates these dependencies but does not measure the effort required to maintain them through repeated updates.

Productivity uncertainty remains even when the model provides suitable quantity information for the selected work scope. Methvin and MEP Academy provide an external basis for the assumptions used in the artifact test, while the interviews show that actual production can vary between crews and can depend on subcontractor input or capacity. Measured local production would provide another basis for the rate. Each source has a different degree of connection to the crew and project represented by the calculation.

The 20% sensitivity example shows how strongly the productivity assumption can affect the calculation. A 20% lower productivity rate increases calculated cycle time by 25%, allowing the interpretation of a planning unit close to the load-adjusted capacity to change without any design change. Meaningful comparison between model or plan states depends on retaining the productivity assumption set together with the version information used for each calculation.

Model information quality remains a technical boundary of the calculation. Reliable room-based surfaces were unavailable, while MEP installation effort included production content beyond the components explicitly represented by the selected length quantities. The formulas can calculate precisely from the selected inputs, yet numerical precision cannot remove uncertainty about what those inputs represent. The defensibility of the result remains dependent on the relationship between the model quantity and the actual production scope.

The design science evaluation therefore supports a bounded claim. The artifact can organize model-derived quantities into zone and work-package planning units, expose the assumptions used to translate those quantities into takt capacity, and preserve selected information for traceability and writeback. Whether its use improves production performance or revision decisions requires evaluation in live projects and across repeated information states.

8.6 Further development of the workflow

Repeated revision cycles provide the first missing test for the version structure. Several dated model states paired with the planning states used at those dates would allow a design change to be followed from changed quantity through recalculation and into any corresponding plan change. The same material would show whether Model_VersionTag and Plan_VersionTag remain manageable when the two version histories develop at different rates.

Productivity validation would strengthen a different part of the calculation. A future project could compare external baseline rates with subcontractor estimates or measured production from the same work packages. This would show how much of the loaded-ratio variation comes from the chosen rate and whether project-specific data changes which planning units appear capacity-sensitive.

Technical work requires development at the quantity level. The current pipe and duct work packages use length as the principal driver, leaving smaller installation content inside average productivity. A richer model could separate additional technical components when those objects exist and when the production process benefits from treating them as separate drivers. The gain would have to be balanced against the additional information required to maintain that detail.

Integration with site follow-up would extend the artifact beyond its current planning-stage role. The calculated workload signal could be compared with actual start, completion, or handover information during production. This would allow later research to examine whether planning units whose cycle times occupy larger shares of the selected load-adjusted capacity are also more likely to show production-stage pressure, connecting the thesis calculation more directly with the type of indicators examined by Riekki et al. (2024).

A larger project application would test the organizational side of the workflow. Multiple takt trains or discipline structures would increase the demand for consistent coding and version control. Such a test could show whether Excel remains manageable as the calculation layer and at what scale the transparent logic developed here becomes difficult to maintain without greater automation. The present study does not establish that transition point.

Across these development paths, the combination of zone and work package provides a common unit for comparison. Model revisions can alter quantity, planning revisions can alter the use of that quantity in the takt structure, and local production data can change its conversion into expected time. Keeping the planning unit consistent would allow these changes to be compared without changing the basic calculation logic each time new information enters the workflow.

9 Conclusion

BIM-based quantity information can support takt planning control when the quantity is connected to the same production unit used by the takt plan. In this thesis, that unit is one work package in one zone. The BIM to Excel to Revit artifact carries scheduled model quantities into this planning structure, converts them into expected duration through productivity assumptions, and compares the resulting cycle time with takt capacity. Selected planning information can then be prepared for communication back to Revit while retaining the quantity and assumption set behind the calculation.

The controlled prototype and project-model application demonstrated different parts of this calculation. The prototype contained one planning unit whose calculated cycle time exceeded the complete takt period and another that remained within it. In the project model, every planning unit had RequiredPeriods equal to one under the final crew-based assumptions. The loaded ratios still varied across work packages and zones because their calculated cycle times occupied different shares of the selected load-adjusted capacity. The workflow can therefore reveal variation in planned capacity use even when a complete-takt overload is absent.

Raw quantity alone cannot identify which work packages are capacity-sensitive. The selected work packages use different physical measures, and each quantity becomes comparable only after its productivity assumption converts it into time. The project results also showed why capacity sensitivity is better represented as a comparative pattern than as a fixed class of watch packages. WP05 Ceiling painting, for example, reached loaded ratios of 0.71 in Z01 and 0.66 in Z02, placing it within the same numerical range as several work packages that otherwise appeared among the higher-loaded cases. Capacity sensitivity therefore describes the relationship between quantity, productivity, and selected load-adjusted capacity under the assumption set used for the calculation.

Model structure affects that relationship before the capacity formula is applied. Interior partitions could use modeled wall area directly, while wall painting required a derived surface calculation and ceiling painting used apartment-zone area because the modeled ceiling objects covered only part of the intended painted surface. Pipework and ventilation were represented through modeled length, with smaller installation content represented through the corresponding productivity assumptions. A planning ratio therefore inherits the production meaning and limitations of the quantity driver from which its cycle time is calculated.

The interview material places the quantity-based calculation within the wider task of takt control. Practitioners described changes in work content that can alter the workload assigned to a zone, which is the type of change the artifact can recalculate when suitable model information is available. They also described conditions such as missing prerequisites and failed handovers that can stop production while leaving the modeled quantity unchanged. The artifact addresses the planned work-content side of takt control, while current production information remains necessary for judging readiness and responding to conditions on site.

Revision support is established through the traceability structure surrounding the calculation. Model_VersionTag identifies the model condition associated with the source quantity, while Plan_VersionTag identifies the planning state that uses that information. Keeping the two states separate allows a quantity-changing model update to be distinguished from a planning change such as resequencing or a changed zone structure. The workflow therefore provides a structure through which later model and plan states can be recalculated and compared while preserving which information state produced each planning output.

Work Density research already connects quantity and production rate with time-based workload for takt planning (Singh et al., 2020; Tommelein, 2022; Singh & Tommelein, 2023). BIM-takt research establishes the need for compatible structures between model information and production planning (Ljung et al., 2023; Viklund Tallgren et al., 2022). The BIM to Excel to Revit artifact brings these research lines together through a production-oriented information path where BIM-derived quantities retain their zone and work-package identity as they enter the capacity calculation. The same path preserves visible calculation assumptions and separates model state from plan state around the resulting planning information.

For contractors and planners, this structure provides a traceable basis for examining calculated workload before the takt matrix is used for production coordination. A capacity signal can be followed back to the zone, work package, source quantity, and productivity assumption that produced it. The project team can then combine that information with its knowledge of crews and current production conditions when deciding how the plan is handled. The resulting planning unit links modeled work content with expected duration and capacity use while keeping the assumptions behind that relationship visible.

9.1 Limitations and future work

The project-model evidence comes from one apartment floor, one usable model condition, and one planning state. The numerical loaded ratios therefore belong to the selected case and its assumption set. Several dated model revisions paired with corresponding takt-plan states were unavailable, so repeated use of the version structure could not be evaluated through an actual project revision history.

Productivity values were derived from external sources and adjusted into crew-based planning assumptions. They were not measured from production in the anonymized project. Since cycle time changes directly with productivity, another contractor or subcontractor rate can change the loaded ratios and, where the change is large enough, the number of takt periods required by a planning unit. Project-specific production data would allow the external assumptions to be compared with rates observed for the same work packages.

Quantity representation remains dependent on the information available in the model. Painting required interpreted quantity rules, while pipework and ventilation used length-based drivers that do not separately quantify all installation components. Manual assignment of Zone ID and Work Package ID also creates an information-control dependency before quantities can be grouped into planning units. A larger application would provide evidence about how these requirements develop when more zones and discipline interfaces enter the workflow.

Further evaluation can extend the workflow into the conditions that remained outside the project-model test. Several dated model and plan states would allow a design change to be followed from changed quantity through recalculation and any corresponding planning change. Production-stage information could then be compared with the calculated planning signal to examine whether planning units using larger shares of load-adjusted capacity also experience pressure during execution. Combining repeated revisions, project-specific productivity information, and a larger model would test whether the same zone and work-package structure remains workable when the amount and frequency of project information increase.

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A

Project model

A.1 Excel settings

Parameter	Value
Project_Name	Hus_G
Model_VersionTag	V01
Plan_VersionTag	TP01
Project_StartDate	2026-04-13
Global_TaktTime_Days	5
LoadFactor	0.7
WarningThreshold	0.85
Paint_Height_m	2.4
Calendar_TaktSpanDays	7

Table A.1: Excel settings used for takt time, load factor, plan start date, and plan version in the project model workbook.

A.2 Excel work packages

WorkPackageID	WorkPackageName	SourceFile	SourceCategory	QuantityDriver	QuantityUnit	BackToRevit
WP01	Interior_Partitions	A	Walls	Area	m2	Yes
WP02	Door_Sets	A	Doors	Count	nr	Yes
WP03	Floor_Finishes	A	Floors	Area	m2	Yes
WP04	Wall_Painting	AK	Walls	LengthPaintHeight*SideFactor	m2	No
WP05	Ceiling_Painting	A	Ceilings	Area	m2	No
WP06	Suspended_Ceilings	A	Ceilings	Area	m2	Yes
WP07	Pipework_Internal	W	Pipes	Length	m	Yes
WP08	Ventilation_Ducts	V	Ducts	Length	m	Yes

Table A.2: Work package list used to connect the project model quantities with the takt planning structure.

A.3 Excel productivity assumptions

The productivity values in Appendix A.3 are planning assumptions used for cycle-time testing. Methvin (n.d.) production-rate data was used as the baseline for the architectural and finishing work packages, while MEP Academy (2020) was used to inform the ductwork assumption. The values were adjusted into crew-based daily rates to fit the project model calculation and are not measured production rates from the actual project.

WorkPackag	ProductivityR	ProductivityU	Notes	CrewSiz	PerInstaller
WP01	80	m2/day	Walls - Methvin's 40 m2/day for 1 installer.	2	40
WP02	4.8	nr/day	Doors - Methvin's 4.8 doors/day for 2 installers.	2	2.4
WP03	40	m2/day	Floors - Methvin's 20-22 m2/day for 1 installer.	2	20
WP04	120	m2/day	Wall painting - Mehtvin's 40 m2/day for 1 painter.	3	40
WP05	32	m2/day	Ceiling painting - Methvin's 32 m2/day for 1 painter.	1	32
WP06	32	m2/day	Suspended ceilings - Methvin's 32-40 m2/day for 1 installer.	1	32
WP07	50	m/day	Pipes - Methvin's 27 m2/day for 1 installer.	2	25
WP08	25.0	m/day	Ducts - MEP Academy, 8-9 m/day for 1 installer.	3	8.33

Table A.3: Productivity assumptions used for the project model cycle-time and overload calculations.

A.4 Excel areas

Name	Area	Takt_ZoneID	Model_VersionTag	Area_m2
Zone 1	79 m²	Z01	V01	79
Zone 3	61 m²	Z03	V01	61
Zone 4	58 m²	Z04	V01	58
Zone 2	74 m²	Z02	V01	74

Table A.4: Apartment zone areas used as input for area-based work packages in the project model.

A.5 Excel model summary

SourceFile	SourceCategory	Takt_ZoneID	WorkPackageID	Model_VersionTag	QuantityValue	QuantityUnit
A	A_Walls	Z01	WP01	V01	175.68	m2
A	A_Doors	Z01	WP02	V01	5.00	nr
A	A_Floors	Z01	WP03	V01	69.55	m2
AK	Walls_Paint	Z01	WP04	V01	208.89	m2
A	Ceilings_Paint	Z01	WP05	V01	79.00	m2
A	A_Ceilings	Z01	WP06	V01	5.53	m2
W	W_Pipes	Z01	WP07	V01	117.41	m
V	V_Ducts	Z01	WP08	V01	57.36	m
A	A_Walls	Z02	WP01	V01	203.99	m2
A	A_Doors	Z02	WP02	V01	6.00	nr
A	A_Floors	Z02	WP03	V01	75.39	m2
AK	Walls_Paint	Z02	WP04	V01	298.10	m2
A	Ceilings_Paint	Z02	WP05	V01	74.00	m2
A	A_Ceilings	Z02	WP06	V01	17.80	m2
W	W_Pipes	Z02	WP07	V01	120.72	m
V	V_Ducts	Z02	WP08	V01	57.79	m
A	A_Walls	Z03	WP01	V01	101.19	m2
A	A_Doors	Z03	WP02	V01	2.00	nr
A	A_Floors	Z03	WP03	V01	54.27	m2
AK	Walls_Paint	Z03	WP04	V01	242.80	m2
A	Ceilings_Paint	Z03	WP05	V01	61.00	m2
A	A_Ceilings	Z03	WP06	V01	10.19	m2
W	W_Pipes	Z03	WP07	V01	110.10	m
V	V_Ducts	Z03	WP08	V01	43.75	m
A	A_Walls	Z04	WP01	V01	214.02	m2
A	A_Doors	Z04	WP02	V01	2.00	nr
A	A_Floors	Z04	WP03	V01	52.23	m2
AK	Walls_Paint	Z04	WP04	V01	265.82	m2
A	Ceilings_Paint	Z04	WP05	V01	58.00	m2
A	A_Ceilings	Z04	WP06	V01	10.19	m2
W	W_Pipes	Z04	WP07	V01	98.12	m
V	V_Ducts	Z04	WP08	V01	38.02	m

Table A.5: Model summary table showing quantities grouped by zone and work package.

A.6 Excel overload calculations

Takt_Zon	WorkPackageID	Model_Versior	SourceFile	QuantityValue	QuantityUnit	ProductivityRate	ProductivityUnit	CycleTime_Days	CycleTime_Rounded	Global_TaktTime_Days	LoadFactor	OverloadRa	OverloadRatio_Lo	OverloadF	ActionSuggestion	BackToRe	RequiredPeri
Z01	WP01	V01	A	175.68	m2	80	m2/day	2.20	3	5	0.7	0.44	0.63	OK	Keep	Yes	1
Z01	WP02	V01	A	5.00	nr	4.8	nr/day	1.04	2	5	0.7	0.21	0.30	OK	Keep	Yes	1
Z01	WP03	V01	A	69.55	m2	40	m2/day	1.74	2	5	0.7	0.35	0.50	OK	Keep	Yes	1
Z01	WP04	V01	AK	208.89	m2	120	m2/day	1.74	2	5	0.7	0.35	0.50	OK	Keep	No	1
Z01	WP05	V01	A	79.00	m2	32	m2/day	2.47	3	5	0.7	0.49	0.71	OK	Keep	No	1
Z01	WP06	V01	A	5.53	m2	32	m2/day	0.17	1	5	0.7	0.03	0.05	OK	Keep	Yes	1
Z01	WP07	V01	W	117.41	m	50	m/day	2.35	3	5	0.7	0.47	0.67	OK	Keep	Yes	1
Z01	WP08	V01	V	57.36	m	24.99	m/day	2.30	3	5	0.7	0.46	0.66	OK	Keep	Yes	1
Z02	WP01	V01	A	203.99	m2	80	m2/day	2.55	3	5	0.7	0.51	0.73	OK	Keep	Yes	1
Z02	WP02	V01	A	6.00	nr	4.8	nr/day	1.25	2	5	0.7	0.25	0.36	OK	Keep	Yes	1
Z02	WP03	V01	A	75.39	m2	40	m2/day	1.88	2	5	0.7	0.38	0.54	OK	Keep	Yes	1
Z02	WP04	V01	AK	298.10	m2	120	m2/day	2.48	3	5	0.7	0.50	0.71	OK	Keep	No	1
Z02	WP05	V01	A	74.00	m2	32	m2/day	2.31	3	5	0.7	0.46	0.66	OK	Keep	No	1
Z02	WP06	V01	A	17.80	m2	32	m2/day	0.56	1	5	0.7	0.11	0.16	OK	Keep	Yes	1
Z02	WP07	V01	W	120.72	m	50	m/day	2.41	3	5	0.7	0.48	0.69	OK	Keep	Yes	1
Z02	WP08	V01	V	57.79	m	24.99	m/day	2.31	3	5	0.7	0.46	0.66	OK	Keep	Yes	1
Z03	WP01	V01	A	101.19	m2	80	m2/day	1.26	2	5	0.7	0.25	0.36	OK	Keep	Yes	1
Z03	WP02	V01	A	2.00	nr	4.8	nr/day	0.42	1	5	0.7	0.08	0.12	OK	Keep	Yes	1
Z03	WP03	V01	A	54.27	m2	40	m2/day	1.36	2	5	0.7	0.27	0.39	OK	Keep	Yes	1
Z03	WP04	V01	AK	242.80	m2	120	m2/day	2.02	3	5	0.7	0.40	0.58	OK	Keep	No	1
Z03	WP05	V01	A	61.00	m2	32	m2/day	1.91	2	5	0.7	0.38	0.54	OK	Keep	No	1
Z03	WP06	V01	A	10.19	m2	32	m2/day	0.32	1	5	0.7	0.06	0.09	OK	Keep	Yes	1
Z03	WP07	V01	W	110.10	m	50	m/day	2.20	3	5	0.7	0.44	0.63	OK	Keep	Yes	1
Z03	WP08	V01	V	43.75	m	24.99	m/day	1.75	2	5	0.7	0.35	0.50	OK	Keep	Yes	1
Z04	WP01	V01	A	214.02	m2	80	m2/day	2.68	3	5	0.7	0.54	0.76	OK	Keep	Yes	1
Z04	WP02	V01	A	2.00	nr	4.8	nr/day	0.42	1	5	0.7	0.08	0.12	OK	Keep	Yes	1
Z04	WP03	V01	A	52.23	m2	40	m2/day	1.31	2	5	0.7	0.26	0.37	OK	Keep	Yes	1
Z04	WP04	V01	AK	265.82	m2	120	m2/day	2.22	3	5	0.7	0.44	0.63	OK	Keep	No	1
Z04	WP05	V01	A	58.00	m2	32	m2/day	1.81	2	5	0.7	0.36	0.52	OK	Keep	No	1
Z04	WP06	V01	A	10.19	m2	32	m2/day	0.32	1	5	0.7	0.06	0.09	OK	Keep	Yes	1
Z04	WP07	V01	W	98.12	m	50	m/day	1.96	2	5	0.7	0.39	0.56	OK	Keep	Yes	1
Z04	WP08	V01	V	38.02	m	24.99	m/day	1.52	2	5	0.7	0.30	0.43	OK	Keep	Yes	1

Table A.6: Overload calculation table showing cycle time, overload ratio, loaded ratio, required periods, and action status by planning unit.

A.7 Excel plan matrix

Takt_ZoneID	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	P11	P12
Z01	WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02			
Z02		WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02		
Z03			WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02	
Z04				WP07	WP08	WP01	WP06	WP05	WP04	BUFFER	WP03	WP02

Table A.7: Project model takt plan matrix showing the planned sequence across apartment zones and takt periods.

A.8 Excel version log

Date	Model_VersionTag	Plan_VersionTag	Takt_ZoneID	WorkPackageID	TriggerCategory	ChangeDescription	ImpactOnQuantity	ImpactOnPlan	ActionTaken	EvidenceSource	Notes
2026-04-13	V01	TP01	Z01	WP07	Labor			Crew increased			
2026-MM-DD											
2026-MM-DD											
2026-MM-DD											
2026-MM-DD											
2026-MM-DD											
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2026-MM-DD											

Table A.8: Version log used to record model version, plan version, and notes connected to the workbook output.

A.9 Excel buffer log

Date	Plan_VersionTag	Takt_ZoneID	Takt_Period	BufferType	PlannedReason	UsedYesNo	UsedFor	Outcome	Notes
2026-05-25	TP01	Z01	P07	Unused	Drying of paint.	No		Unused	
2026-06-01		Z02	P08						
2026-06-08		Z03	P09						
2026-06-15		Z04	P10						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
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#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						
#VALUE!		#VALUE!	#VALUE!						

Table A.9: Buffer log used to record planned buffer placement and the reason for including buffer time in the takt matrix.

A.10 Excel BackToRevit exports

SourceFile	Takt_ZoneID	Takt_WorkPackageID	Takt_Period	Plan_VersionTag	PeriodIndex	Takt_Start	Takt_End	IsBuffer	BackToRevit
W	Z01	WP07	P01	TP01	1	2026-04-13	2026-04-19	No	Yes
A	Z01	WP01	P03	TP01	3	2026-04-27	2026-05-03	No	Yes
V	Z01	WP08	P02	TP01	2	2026-04-20	2026-04-26	No	Yes
A	Z01	WP02	P09	TP01	9	2026-06-08	2026-06-14	No	Yes
A	Z01	WP03	P08	TP01	8	2026-06-01	2026-06-07	No	Yes
A	Z01	WP06	P04	TP01	4	2026-05-04	2026-05-10	No	Yes
AK	Z01	WP04	P06	TP01	6	2026-05-18	2026-05-24	No	No
A	Z01	WP05	P05	TP01	5	2026-05-11	2026-05-17	No	No
	Z01	BUFFER	P07	TP01	7	2026-05-25	2026-05-31	Yes	No
W	Z02	WP07	P02	TP01	2	2026-04-20	2026-04-26	No	Yes
V	Z02	WP08	P03	TP01	3	2026-04-27	2026-05-03	No	Yes
A	Z02	WP01	P04	TP01	4	2026-05-04	2026-05-10	No	Yes
A	Z02	WP06	P05	TP01	5	2026-05-11	2026-05-17	No	Yes
A	Z02	WP05	P06	TP01	6	2026-05-18	2026-05-24	No	No
AK	Z02	WP04	P07	TP01	7	2026-05-25	2026-05-31	No	No
	Z02	BUFFER	P08	TP01	8	2026-06-01	2026-06-07	Yes	No
A	Z02	WP03	P09	TP01	9	2026-06-08	2026-06-14	No	Yes
A	Z02	WP02	P10	TP01	10	2026-06-15	2026-06-21	No	Yes
W	Z03	WP07	P03	TP01	3	2026-04-27	2026-05-03	No	Yes
V	Z03	WP08	P04	TP01	4	2026-05-04	2026-05-10	No	Yes
A	Z03	WP01	P05	TP01	5	2026-05-11	2026-05-17	No	Yes
A	Z03	WP06	P06	TP01	6	2026-05-18	2026-05-24	No	Yes
A	Z03	WP05	P07	TP01	7	2026-05-25	2026-05-31	No	No
AK	Z03	WP04	P08	TP01	8	2026-06-01	2026-06-07	No	No
	Z03	BUFFER	P09	TP01	9	2026-06-08	2026-06-14	Yes	No
A	Z03	WP03	P10	TP01	10	2026-06-15	2026-06-21	No	Yes
A	Z03	WP02	P11	TP01	11	2026-06-22	2026-06-28	No	Yes
W	Z04	WP07	P04	TP01	4	2026-05-04	2026-05-10	No	Yes
V	Z04	WP08	P05	TP01	5	2026-05-11	2026-05-17	No	Yes
A	Z04	WP01	P06	TP01	6	2026-05-18	2026-05-24	No	Yes
A	Z04	WP06	P07	TP01	7	2026-05-25	2026-05-31	No	Yes
A	Z04	WP05	P08	TP01	8	2026-06-01	2026-06-07	No	No
AK	Z04	WP04	P09	TP01	9	2026-06-08	2026-06-14	No	No
	Z04	BUFFER	P10	TP01	10	2026-06-15	2026-06-21	Yes	No
A	Z04	WP03	P11	TP01	11	2026-06-22	2026-06-28	No	Yes
A	Z04	WP02	P12	TP01	12	2026-06-29	2026-07-05	No	Yes

Table A.10: BackToRevit export table showing the planning fields prepared for Revit writeback.

A.11 Revit parameter and schedule setup

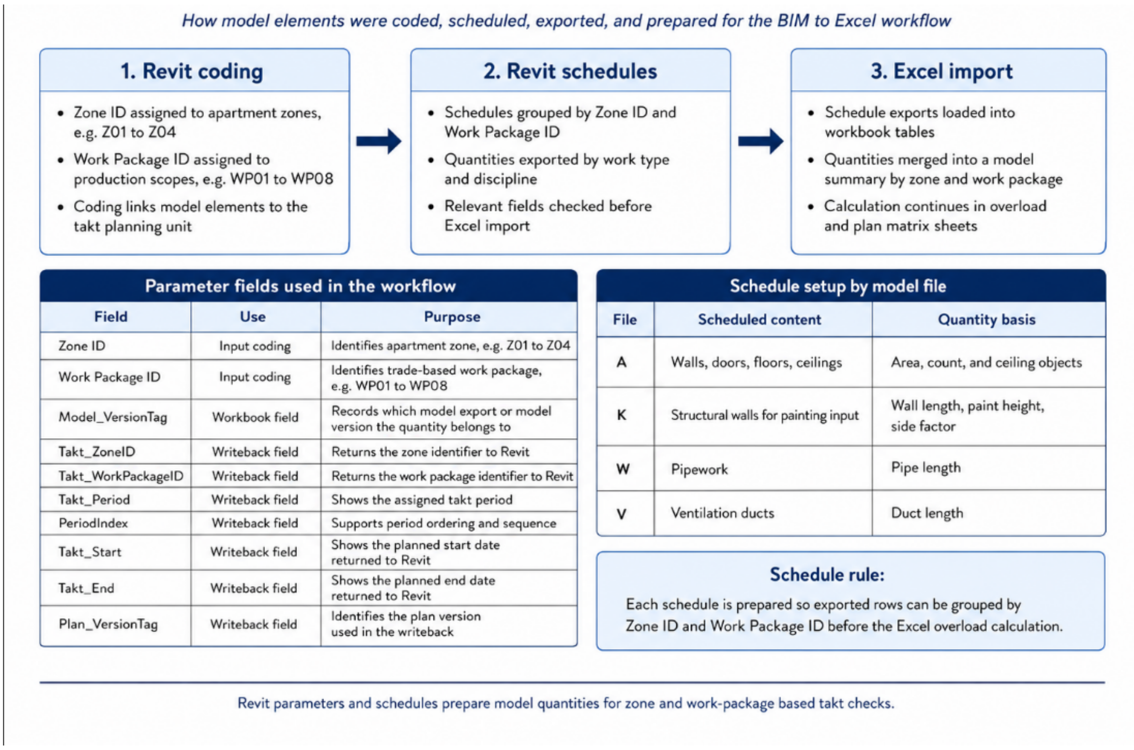

Figure A.11: Revit parameter and schedule setup used to connect model elements with zones, work packages, and writeback fields.

A.12 Excel lists and dropdown values

TriggerCategory	ImpactScale	YesNo	BufferType	WorkPackageID	Takt_ZoneID	Plan_VersionTag	Model_VersionTag	Takt_Period	ImpactOnPlan	Outcome
Design	None	Yes	Planned recovery	WP01	Z01	TP01	V01	P01	No change	Unused
Drying	Low	No	Trade catch-up	WP02	Z02	TP02	V02	P02	Rebalanced	Fully used
Labor	Medium		Drying / curing	WP03	Z03	TP03	V03	P03	Buffer inserted	Partly used
Logistics	High		Inspection / approval	WP04	Z04	TP04	V04	P04	Shifted one takt	Insufficient
Other			Material delay protection	WP05		TP05	V05	P05	Crew increased	Helped recover flow
			Design clarification	WP06		TP06	V06	P06	Split package	
			Rework	WP07		TP07	V07	P07	Other	
			Unused	WP08		TP08	V08	P08		
			Other	BUFFER		TP09	V09	P09		
						TP10	V10	P10		
								P11		
								P12		

Table A.12: Excel list and dropdown values used to standardize workbook inputs and reduce inconsistent entries.

A.13 Revit Dynamo writeback process

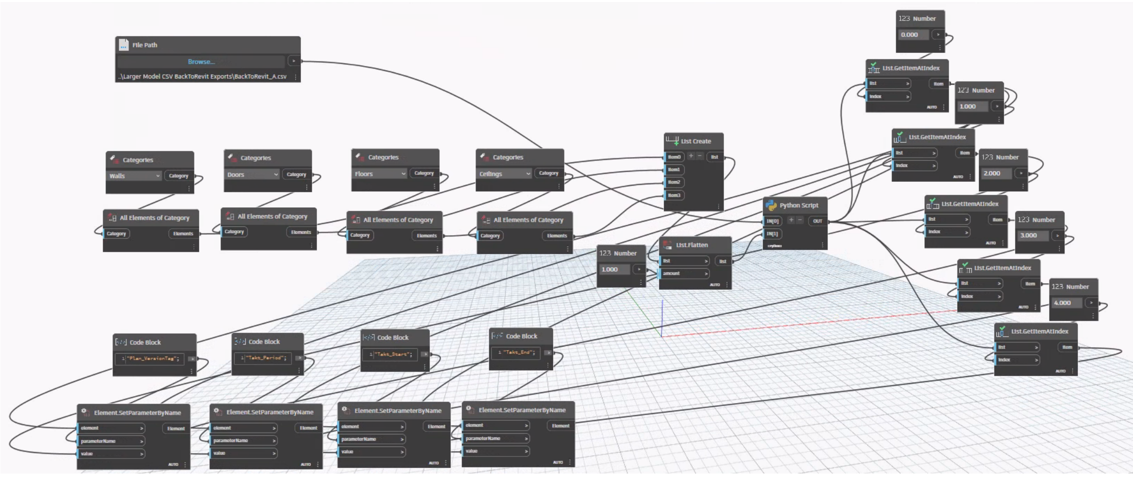

Figure A.13: Dynamo writeback node structure used to read the BackToRevit CSV export and write Takt_ZoneID, Takt_WorkPackageID, Takt_Period, PeriodIndex, Takt_Start, Takt_End, and Plan_VersionTag to matching Revit parameters.

B

Prototype model and controlled test outputs

B.1 Prototype input quantities

Takt_ZoneID	Takt_WorkPackageID	Area	Model_VersionTag
Z01	WP01	638	V01
Z02	WP01	627	V01
Z03	WP01	962	V01
Z04	WP01	216	V01

Takt_ZoneID	Takt_WorkPackageID	Model_VersionTag	Length
Z01	WP02	V01	27.974
Z02	WP02	V01	27.032
Z03	WP02	V01	25.155
Z04	WP02	V01	24.512

Table B.1: Prototype input quantities for walls and pipes used to test area-based and length-based quantity logic.

B.2 Prototype settings and productivity assumptions

Global_TaktTime_Days	Project_StartDate	WarningThreshold	Plan_VersionTag
7	2026-03-02	0.9	TP01

WorkPackageID	ProductivityRate	ProductivityUnit	QuantitySource	Notes
WP01	100	m2/day	WallsArea	placeholder
WP02	4	m/day	PipesLength	placeholder

Table B.2: Prototype settings and productivity assumptions used for the controlled model test.

B.3 Prototype overload calculation

Takt_ZoneID	Takt_WorkPackageID	Model_VersionTag	QuantitySourc	QuantityValu	QuantityUnit	ProductivityRate	ProductivityUnit	CycleTime_Days	CycleTime_Rounded	Global_TaktTir	OverloadRati	OverloadFlag
Z01	WP01	V01	WallsArea	638	m2	100	m2/day	6.38	7	7	1	0
Z02	WP01	V01	WallsArea	627	m2	100	m2/day	6.27	7	7	1	0
Z03	WP01	V01	WallsArea	962	m2	100	m2/day	9.62	10	7	1.428571429	1
Z04	WP01	V01	WallsArea	216	m2	100	m2/day	2.16	3	7	0.428571429	0
Z01	WP02	V01	PipesLength	27.974	m	4	m/day	6.9935	7	7	1	0
Z02	WP02	V01	PipesLength	27.032	m	4	m/day	6.758	7	7	1	0
Z03	WP02	V01	PipesLength	25.155	m	4	m/day	6.28875	7	7	1	0
Z04	WP02	V01	PipesLength	24.512	m	4	m/day	6.128	7	7	1	0

Table B.3: Prototype overload calculation showing how cycle time and overload ratio were calculated from quantity and productivity assumptions.

B.4 Prototype plan matrix

Takt_ZoneID	P01	P02	P03	P04	P05
Z01	WP01	WP02			
Z02		WP01	WP02		
Z03			WP01	WP02	
Z04				WP01	WP02

Table B.4: Prototype plan matrix showing how the calculated work packages were arranged into a takt sequence.

B.5 Prototype BackToRevit export

Takt_ZoneID	Takt_Period	Takt_WorkPackageID	Plan_VersionTag	PeriodIndex	Takt_Start	Takt_End
Z01	P01	WP01	TP01	1	2026-03-02	2026-03-08
Z01	P02	WP02	TP01	2	2026-03-09	2026-03-15
Z02	P02	WP01	TP01	2	2026-03-09	2026-03-15
Z02	P03	WP02	TP01	3	2026-03-16	2026-03-22
Z03	P03	WP01	TP01	3	2026-03-16	2026-03-22
Z03	P04	WP02	TP01	4	2026-03-23	2026-03-29
Z04	P04	WP01	TP01	4	2026-03-23	2026-03-29
Z04	P05	WP02	TP01	5	2026-03-30	2026-04-05

Table B.5: Prototype BackToRevit export showing the selected planning fields prepared for model writeback.

C

Interview guide

The following interview guide was used as the basis for the semi-structured interviews. Since the interviews were semi-structured, the wording, order, and follow-up questions were adjusted depending on the interviewee's role, project experience, and answers.

Introduction and consent:

The interview began with a short introduction to the thesis topic and a request for permission to record and transcribe the meeting. The interviewee was informed that the material would be treated anonymously and that names of individuals, companies, and projects would not be disclosed in the thesis.

Background and role:

1. What is your current role, and how does your work relate to takt planning or takt control?
2. What practical experience do you have with takt planning?
3. In what type of projects have you worked with takt planning?
4. How is takt planning usually followed up in practice on site?

Takt zones and work packages:

1. How are takt zones usually defined in the projects you have worked with?
2. How are work packages usually defined?
3. How do you make sure that the workload is reasonably balanced between zones?
4. Are some areas, such as technical rooms, staircases, corridors, or special rooms, treated differently from the main takt flow?

Conditions for locking the takt plan:

1. What information needs to be stable enough before a takt plan can be considered reliable enough for execution?
2. What design, quantity, procurement, logistics, or resource information is most important at that stage?
3. What usually remains uncertain even after the takt plan has been locked?

Design updates, quantity changes, and missing prerequisites:

1. How do design updates or quantity changes usually reach the planning team or site team?
2. How do late design changes affect takt planning and takt control in practice?
3. How are missing prerequisites, such as incomplete drawings, delayed materials, or blocked work areas, handled?
4. How do you judge whether a change can be absorbed within the existing plan or requires replanning?

Detecting problems during execution:

1. How do you notice that takt is starting to fail before it fully breaks?
2. What warning signs, indicators, meetings, reports, or digital updates are used to detect problems early?
3. How are incomplete work, delayed starts, missing materials, or poor handovers made visible?

Follow-up routines and takt control:

1. What follow-up routines are most important for keeping the takt plan stable?
2. How often is the takt plan reviewed with supervisors, subcontractors, or trade representatives?
3. How are upcoming constraints checked before the next takt period begins?
4. Who is responsible for checking whether a zone is ready for the next trade?

Replanning and adjustments:

1. What usually causes the takt plan to be revised during execution?
2. In practice, are design changes, logistics problems, labor issues, quality issues, missing prerequisites, or uneven workloads the most common causes?
3. When delay or overload occurs, what is usually adjusted first?
4. How do project teams decide between adding workers, using overtime, changing sequence, changing zones, changing takt time, adding buffers, or pausing production?

Documentation and digital support:

1. Are changes to the takt plan usually documented in a structured way?
2. Where are changes and decisions documented, for example in meeting minutes, logs, version history, digital systems, or deviation reports?
3. Do you use any digital system to follow takt progress during execution?
4. What role can BIM-based quantity information or structured data play in supporting more reliable takt planning and control?
5. What is still missing in practice for digital support to work better?

Real project example:

1. Could you describe one real project or case where takt planning was used and the plan had to be changed or adjusted?
2. What caused the change?
3. Who identified the issue, and who made the decision to adjust the plan?
4. What changed in the plan, for example zones, sequence, crew size, takt time, logistics, or work packages?
5. Was the reason documented formally or handled more informally?
6. Did the adjustment solve the issue, or did it create new problems?

Closing questions:

1. What is the biggest challenge in keeping a takt plan stable during interior works?
2. What improvement would reduce replanning the most?
3. Is there anything else you would like to add?
4. Would it be acceptable to follow up later with one or two clarifying questions if needed?

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