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Takt Planning in Apartment Building Renovation Projects

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Received: 5 October 2020; Accepted: 1 December 2020; Published: 4 December 2020

Abstract: Takt production has been of great interest in construction during the last few years. In this research, a case study was carried out to demonstrate how the scheduling of an apartment building renovation project that utilizes takt production can be done. Furthermore, the study defines what clarifications should be made into the existing takt production models in the context of apartment building renovation projects, and it also explains why. Based on the study, adhering to a uniform production rate is challenging in apartment renovation projects. Therefore, a total of five clarifications to existing takt production methods are suggested. (1) Production with short takt requires a highly detailed definition of tasks in order to avoid ambiguousness. (2) Some tasks carried out in takt areas may have to be excluded from takt production. (3) The sensitivity of a created takt schedule should be evaluated, and buffers should be added accordingly. (4) Emphasis must be put on coordinating takted and non-takted tasks. (5) Takt plan modification during production requires effective procedures, since there is little time to react.

Keywords: takt production; lean construction; takt planning; building renovation; action research; case study

1. Introduction

Practices familiar from the manufacturing industry are utilized in construction more and more. One of these methods is takt production, which several construction projects have sought to take advantage of during the last decade or so, e.g., [1–12]. However, there are no comprehensive guidelines for the planning of a takt production model, and only a few articles concerning takt planning have been published. In particular, the application of takt planning in refurbishment has not been studied much even though the volume of refurbishment is increasing in several countries and has, in part, already surpassed new construction. The adoption of takt production especially in apartment building renovation projects may be fruitful, as apartment buildings have often been mass produced. Such mass produced buildings are particularly suitable for the application of a takt production, which is effective for utilizing repetition [4,13]. In general, renovation differs from new construction in several different factors, merely because the existing building and its constraints must be taken into account in both building design and production planning. Since renovation differs from new construction in several different factors, utilizing takt production in the context of renovation projects must be addressed.

The purpose of this study is to demonstrate how the scheduling of an apartment building renovation project that utilizes takt production can be done, as well as what factors affect the scheduling. In addition, the study defines what clarifications and why should be made in existing takt planning methods in the context of apartment building renovation. The purpose of this study is not to answer whether takt production is an improvement over prevalent production methods.

The article is based on a case study of an apartment building renovation project, in the production planning of which the main author of the article participated. Thus, the research method is action research.

2. Theoretical Background

2.1. The Definition of Takt Production

Takt production means equalizing the production rates of different trades [5]. Through uniform production rates, a situation where the progress of quicker tasks is disturbed because of slower tasks can be avoided [14].

In takt production, all tasks included in it are scheduled to start and be finished within takts of equal duration [12]. Thus, trades move from one work site to another at consistent intervals. The period of time between two such intervals is called a takt time [8]. The takt time defines how long each trade reserves individual work sites [6]. When the objective is to get workers to work at a mutually agreed production rate, the takt time is the basis for that rate [8].

Takt production differs from other production methods particularly in that in takt production, every trade must finish their work in a given work site within the uniform time period: the takt time [1]. To ensure a steady progress of production, all possible contingencies that could cause variance in the production rate are eliminated in takt planning. For example, work sites that differ from one another or unclear production planning may cause variance. After this, trades are underloaded, i.e., less work is addressed to them than what they could do. The purpose of underloading is to ensure that jobs that take longer than expected do not delay production [15].

When several different trades must work together, the coordination of work between the trades is essential. The progress of the work of different trades cannot be monitored at all times. Furthermore, despite takt production, work does not always progress at the same pace within takt areas. It is important that takt areas are finished within the cycle defined by the takt time so that work can continue without interruption in the next takt [8]. A takt area refers to an area where an individual work package is carried out during each takt [13]. A work package defines the work that is carried out during each takt in each takt area [13].

More milestones are set for the production when the takt time is set at a short time period [3]. The smaller the segments that the production is divided into, the more detailed the production plan can be, and the less ambiguity there is in production monitoring [16]. Even though observing and correcting mistakes daily requires a lot of monitoring, it prevents delays from building up and develops the production flow [9].

2.2. Takt Planning and Management

Two models have been published for takt planning. The first model drafted for takt planning comes from the United States [5,7]. The second model comes from Germany and—unlike the first model—it addresses both takt planning and production control [3,4,13,17,18].

2.2.1. Takt Production Model by Frandson et al.

In the model by Frandson et al. [5], the site is divided into takt areas with the target of creating workloads of equal duration. The objective is to spread the workload of each takt to align production rates. According to Frandson et al. [5], the production rate is not equalized to a takt time of uniform length instantly, but the process requires constant development as the production advances. After gathering production-related information and defining trade sequences and takt areas, a first-run study is carried out for the tasks in one takt area. The actual production rates of the tasks in the first takt area are documented. Based on this information, the production rates are adjusted as the production advances [5,6].

Another characteristic feature of the model by Frandson et al. [5] is involving subcontractors in the planning process before the beginning of production. The trade sequence is roughly defined via pull planning. The information needed for takt planning is gathered together with subcontractors' foremen. The subcontractors' foremen determine together how, by whom, where, and in which order work needs to be done. Meetings that include joint planning are held during the entire duration of the takt planning to utilize the expertise of the subcontractors' foremen.

2.2.2. Takt Production Model by Dlouhy et al.

In the takt production model by Dlouhy et al. [13], takt areas are defined by first dividing the site into different functional areas. Every construction zone with a significantly different work content constitutes a functional area and requires separate takt planning [3]. After the definition of takt areas, standard space units (SSU) of each area are specified. The SSUs are combined into takt areas that enable a steady production rate [13]. In the model, takt production is planned to be carried out at a uniform production rate from the start. The production rates are equalized based on assessments made beforehand. In the beginning of production, efficiency is lower due to, for example, practicing and adjusting to the production model [19]. This is why the Dlouhy et al. [13] model recommends using a so-called "soft start" in the beginning, i.e., a reduced workload per takt [19]. The production model is not static: it is adjusted in daily takt meetings as necessary [17].

In the Dlouhy et al. model [13], the takt schedule is presented in a form that slightly resembles a line of balance schedule [13,18,19]. In the takt schedule, tasks are not depicted as lines, but as takt area and takt time-specific packages, which are called "wagons" [13]. At present, this takt schedule model that visualizes work packages, takts, and takt areas has become widespread as the schedule model in takt production projects [1,9,11,17].

The takt production model by Dlouhy et al. [13] separates takt planning and takt control in takt production. In this model, the content of work is defined on the work package level and, in more detail, as work steps, which are placed in the work packages. As a short takt time sets constant milestones for tasks, they must be constantly steered in order to control schedule deviation. The purpose of takt control is to control individual tasks by reacting swiftly and accurately. The takt schedule is a constantly evolving plan that must be developed as the production progresses. Thus, honing the takt production plans with short notice is important. Making a catch-up plan is much harder if production is not constantly monitored. The purpose of takt control is to maintain the evenness of production that takt production requires [8].

In the takt production model by Dlouhy et al. [13], production plans are refined, if necessary, to meet the true current situation in daily, often quite short (e.g., 15 min) takt meetings. A takt time of more than one day permits taking daily correctional actions in the daily meetings before the takt is exceeded. In addition to members of the organization itself, workers and responsible foremen of partners participate in the takt meetings, documenting the actual situation and meeting the requirements set for the production need to be considered in the takt meetings [13]. Table 1 summarizes the comparison of the two aforementioned takt production models.

Table 1. Comparison of the Frandson et al. and Dlouhy et al. takt production models.

		Takt Model Contains	Frandson et al. (2013)	Dlouhy et al. (2016)
Before production	Takt planning	Pull planning	X	-
		Critical path method	X	-
		Task duration definition	X	X
		Trade/task sequence	X	X
		Work zone/takt area definition	X	X (detailed)
		Work packages	X	X
		Task duration harmonization	X	X
		Soft start	-	X
During production		First run studies	X	-
	Takt control	Daily takt meetings	-	X
		Takt plan monitoring and updating during production	-	X

3. Research Methods and Materials

The results of the study are based on the renovation project of a student housing apartment building that was the case site. The case site was located in Finland. The research method utilized was action research. The main author of this article participated in the planning and development of the takt production of the case site in cooperation with the main contractor's foremen during 2019. The authors had the opportunity to affect the production plans; however, in the end, the foremen were accountable for the success of the project and therefore had the final decision. However, a consensus was quite easily reached between the parties during the project, and therefore, the roles and responsibilities were not perceived to affect the study.

The production was studied in situ all the way throughout the project by the main author. A documented actualized work package and takt area-specific task duration data were collected from the site by the research group daily during the entire project, except for a few days, and the production model was developed based on the gathered information.

The case site consisted of the renovation of five buildings (Figure 1) and altogether approximately 200 apartments, in which indoor surfaces, bathrooms, kitchen fixtures, and all building services systems, such as water and plumbing, ventilation, and electrical systems, were renewed. The roofing of the buildings was renewed as well, and renovation in the outdoor areas were also carried out, including the renewal of sub-surface drains.

Figure 1. Layout of the studied case area. The case site included five apartment buildings that were refurbished in the order indicated by the blue boxes.

Nearly all residential floors in the buildings were identical. A residential floor had four shared apartments, each of which had three rooms, a bathroom, and a shared kitchen. In addition, there were two one-room apartments and one two-room apartment on each floor (Figure 2). Prior to the renovation, instead of the one-room apartments, there was another two-room apartment that was divided into two one-room apartments.

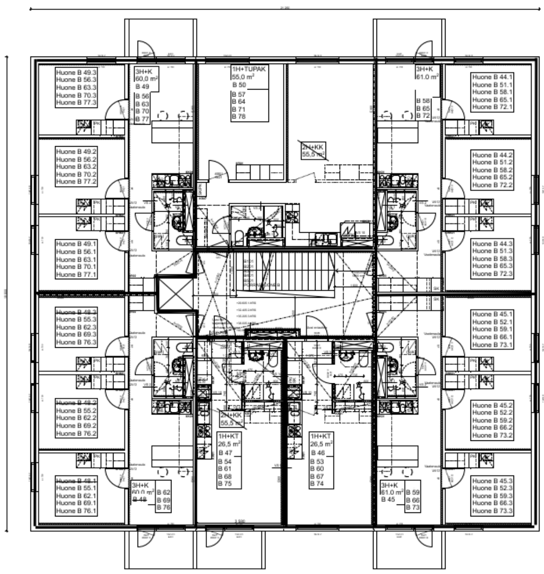

Figure 2. Floor plan of a residential floor of the case site.

The content of the renovation is specified in more detail in Tables 2 and 3. The renovation began in December 2018 and was finished in January 2020. Takt production was utilized in the interior renovation of the apartments but not in the renewal of building service risers. Other renovation work was not carried out as takt production, i.e., the progress of this work was not equalized to fit the progress rate of the takt production.

Table 2. Non-takt work and work done outside of the apartments on the case site.

Stairway	Building Services Systems in the Stairway
Demolition Asbestos demolition Core drilling Floor grinding Staircase grinding Wall duct passage cutting Electrical conduit installation into duct passages Duct passage filling Wall leveling Wall painting Floor surface installation Suspended ceiling installation	Cable racks Electrical risers and cables into apartments Water risers Horizontal water pipes into apartments Shared sauna and washroom renovation Shared laundry room renovation Fittings and fixtures
Roof	**Cellar**
Rain protection Demolition Removal of filler materials Core drilling Ventilation drain installation Roof ventilator installation Installation of filler materials Roofing installation	Demolition Core drilling Cured-in-place pipe lining of the sanitary sewer Floor surface installation Wall painting Shared sauna and washroom renovation Shared laundry room renovation Building services engineering in the cellar Fittings and fixtures

Table 3. Takt work in the apartments in the case site.

Inside Apartments: Wet Room Renovation	Inside Apartments: Dry Room Renovation
Demolition Asbestos demolition Floor grinding Core drilling Wall duct passage cutting Electrical conduit installation into duct passages Duct passage filling Floor drain, fireproofing, and floor drain cast Underfloor heating installation Mesh reinforcement and floor cast Wall leveling Bathroom riser duct fireproofing and insulation Bathroom riser duct encasement Water proofing Floor and wall tiling and seaming Exposed water pipes installation Suspended ceiling insulation (plumbing and ventilation) Suspended ceiling paneling Fitting and fixtures	Demolition Asbestos demolition Floor grinding Core drilling Kitchen–living room plumbing, ventilation Rough concrete wall repair Floor leveling Wall leveling Wall painting Lowered ceiling installation in the entryway Floor surface installation Door frames and doors installation Baseboard installation Fittings and fixtures installation
Inside apartments: building services systems	
Electrical casing (surface installation) Electrical wiring Electrical fixtures Horizontal water pipes Drainage: riser and horizontal installations (kitchen and bathroom) Ventilation riser and horizontal installations (kitchen and bathroom) Original radiators: detachment, flushing, painting, reattachment	

4. Results

In the takt planning of the site, the Dlouhy et al. [13] model presented above was used. The choice was particularly influenced by the fact that the main contractor already had experience of using a similar takt production model on a previous site. The production takt time was set at two working days, the takt area was half a floor (3–4 apartments, a constant number of square meters), and the construction lead time for each building was agreed with the client to be four months. The length of the takt time and the takt area division were defined based on the previous takt production project experience of the main contractor's foremen. A longer takt time was considered to be too long for the interior work phase of an apartment building site, and shortening the takt time would have required a more rapid response to deviations, which was seen as a risk in a pilot project.

In the first building, the takt areas were planned to comprise three apartments. However, this caused the takt areas to be different on each floor, as there were seven apartments on each floor. After the first building, the takt area division was seen to be flawed, as it did not allow for the takt production to be adhered to and monitored. Thus, the takt area division was revised to cover half a floor (3 and 4 apartments, equal square meters), because then, the takt areas were identical on every floor.

Such areas were selected for takt production that included a lot of repetition, as takt production is best utilized on work sites that involve repetition. The functional area that was selected to be completed through takt production were the apartments, as they were identical from floor to floor. The bathrooms (so-called "wet areas") of the apartments were chosen as separate takt areas, as the bathroom work content was very similar irrespective of the apartment. Other rooms in the apartments (so-called "dry areas") also included a lot of identical tasks (leveling, painting, floor surface installation, electrical work, and installing fixtures), which is why the dry areas were selected as a separate takt area. The kitchen differed partly from other rooms due to certain fixture and building service installations. However, the kitchen was included in the dry area takt production, as the renovation of the kitchen was not as busy and laborious as that of the bathroom. The work contents of the wet and dry areas were very different, which is why they were divided into two parallel production trains, as presented in Figure 3.

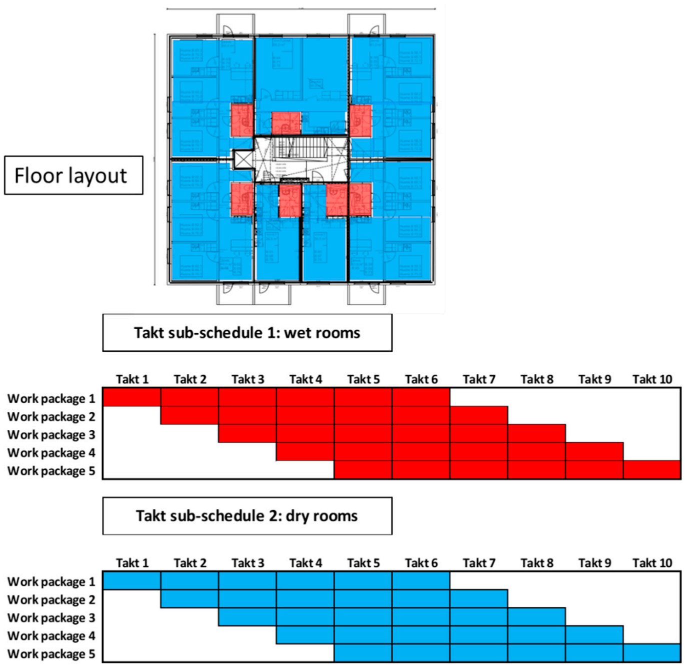

Figure 3. In the apartment building takt production, the execution of bathrooms and other rooms were selected as separate production trains.

Based on the choices described above, the takt schedule depicted in Figure 4 was drafted. The takt production work packages for the dry and wet areas in the apartments were presented separately per takt area in the takt schedule. Each work package in the schedule includes two numbers separated by a period. The first number refers to the floor number, and the second number refers to the takt area in the floor. In addition, apartment riser tasks that affected the takt production were visible in the schedule. The takt schedule followed the Dlouhy et al. [13] takt schedule presentation.

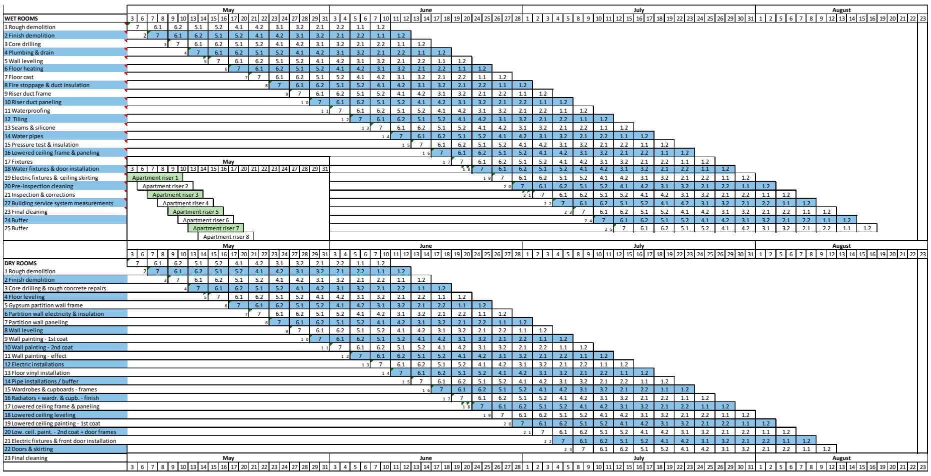

Figure 4. The takt schedule drafted for the case project.

Apart from the last one, every case site building was handed over with four-month intervals as had been agreed with the client. The approximately two-week delay in the final building was caused by a delay in renovation of a day-care center in the previous building. The renovation of the day-care center took longer than planned, and thus, the resources shared with the takt production were engaged in the day-care center for longer than expected. The day-care center was located on the ground floor and had been scheduled to be finished by the handover of the building. As a result of this, there was an interruption of about two weeks in the renovation of the next building, as both the resources and supervision were concentrated on finishing the day-care center by the handover date. If separate resources had been reserved for the day-care center, the takt production in the next building had not been disrupted despite the delays.

Factors that Hinder the Implementation of the Schedule

The coordination of work included in the takt production and work outside it caused difficulties. In particular, there were challenges in coordinating the cellar, roofing, and apartment trade sequences. Waterproofing the bathrooms in the apartments required gypsum duct enclosement, which was possible after service installations inside the duct, which, in turn, required demolition and core drilling work in the cellar and on the roof. Thus, the installation of the weather protection scaffolding had to be started already two weeks before the residents moved out, which was not originally taken into account.

The route of the trades on the case site was similar for most of the time (from the top floor down, one floor at a time). There were some exceptions to this: for example, building service riser work that was done in the usual manner from the bottom up, one riser at a time. Trades proceeding in different directions collided with one another on the work sites. To anticipate collisions of trades, the collisions of work progressing according to schedule were defined, and the optimal trade sequence for overlapping work was considered.

Another problem was that the schedule contained work that could not be carried out at a uniform production rate. For example, the replacement of balcony doors and windows for the apartments had been separately subcontracted and included in the takt production, even though completing this particular task took approximately one work week per building. The progress rate of the takt production work packages had been planned at 12–14 workdays per building, which meant that the subcontractor installing the windows and balcony doors would have had to slow down its rate to a third. It was not possible for the subcontractor to slow down its production rate to correspond to the takt production, which is why the balcony doors and windows were installed at a significantly faster rate than the takt production. In addition, the replacement of windows and doors that was carried out rapidly hardly caused a disturbance to other renovation in the apartments.

Due to the difficulty of following a uniform production rate, the demolition and core drilling phase were also separated from the takt production into tasks that proceeded as swiftly as possible. Demolition and core drilling were tasks that caused a lot of noise, dust, and disturbance. A quick demolition phase allowed for more time to study the work sites and carry out measurements and markings. Thus, it would have been possible to notice, for example, possible hidden water damages discovered during the demolition early on, and the water damage could have been dried out in good time before the beginning of the takt production on the work site in question.

The planned work packages were defined on a level too rough, which is why the work packages were not always finished in one go, and unfinished work packages were marked as finished. The tasks being too roughly defined also brought challenges to production monitoring, because there was ambiguity in the definition of tasks, and sometimes, tasks were not completed in one go, and small partial tasks were left unfinished for days or even weeks. Thus, there was ambiguity regarding the actual progress of work in monitoring documents, as the small delayed job performances included in tasks could not be separately marked as finished. Unit price subcontracts that encouraged the subcontractor to accumulate small and laborious tasks into larger sets, as it was not obligated that tasks be completed at once, also had a negative impact on the completion of work packages as planned.

5. Discussion

One glaring issue with the publications regarding takt production in construction is that the current published research relies almost solely on conference papers published on a yearly basis. Information regarding the planning of takt production is scattered across numerous short papers from a multitude of authors. In some cases, the information is also vague. As a result, understanding takt planning as a cohesive procedure is challenging. This also makes forming a synthesis from the existing literature challenging.

Adopting takt production in an apartment building renovation project was found to be a clear research gap in the existing literature. Existing, more general takt literature was utilized as a basis for this study, in order to implement it into a renovation project. The implementation and utilization processes were studied, and some deficiencies in the existing literature were found in this context. During the peer-review process of this paper, a multi-case study was published by Lehtovaara et al. [10], synthesizing some of the principles of takt production in construction.

Takt planning deficiencies that hinder the implementation of takt production in renovation projects that are not covered in the models by Frandson et al. [5] and Dlouhy et al. [13] were observed on the case site. These deficiencies include:

- Lack of instructions regarding detailed takt planning;
- Takt plan disturbance sensitivity consideration;
- Takt plan risk analysis;
- Coordination of non-takt and takt production phases;
- Enabling an effective takt plan modification processes during production.

Next, these deficiencies are examined, and solutions are presented to them based on the observations made in the case project of this study. Thus, the object of the examination is to bring forward deficiencies related to takt planning in renovation projects and proposals to supplement takt planning to fix these deficiencies. To develop previously published takt planning models, the following supplementary proposals, which are discussed in more detail next, were drafted:

1. Production with a short takt time requires more detailed task definition and pre-emptive planning.
2. Some tasks carried out in takt areas may have to be excluded from takt production.
3. The busyness and disturbance sensitivities of work packages have to be reviewed after drafting a takt plan.

4. Takted and non-takted tasks must be coordinated.
5. Takt plan modification during production should utilize digital planning, data gathering, and analysis.

5.1. Production with a Short Takt Time Requires More Detailed Task Definition and Pre-Emptive Planning

Based on this study, the takt production of a renovation site must, at least when it comes to a residential building, be planned with such precision that the trade groups required for each work package and a feasible order of execution of the work steps included in the work packages can be seen from the production plan without ambiguity. Work packages must be itemized on such a level of detail that no ambiguity remains in completing them. Works should be planned on the level of detail shown in Table 4, as then, the tasks, their order, and trades are clearly specified, which makes it easier to form work packages. This finding adds to the takt planning process described by Binninger et al. [3] and Dlouhy et al. [13]. When carefully planned, work is not uncontrollably interrupted due to small installations by other trade groups and work packages can be smoothly completed during the takt. Regarding this, Binninger et al. [20] have noted that when equalizing production rates, uncertain parts of the process must be planned with particular care in order to minimize the chance of mistakes. The usefulness and importance of dividing takt production into small segments has already been recognized by other authors (e.g., [16]). Among other things, a lack of detailed takt planning caused challenges in the case project and has done so in other projects referenced previously (e.g., [1,10]). According to Lehtovaara et al. [10], all of the six cases they studied had issues with subtasks being left undone. This was partly due to unclarity regarding what subtasks work packages included and communicating this to every participant [10]. However, the finding made in this study is addressed, as there seems to be ambiguity in existing models regarding this topic. The objective here is to highlight and clarify how tasks should be planned at the very least in similar renovation projects as the case project.

Table 4. The production process can be defined on different levels of detail. Precise planning defines the trade sequence and the trades required in tasks.

Level 1 (Lead Time)	Level 1.1 (Task)	Level 1.1.1 (Sub-Tasks)	Trade
Apartment (or bathroom) lead time	**Core drilling**	Passages for HVAC from stairway into apartments	Core drill crew
		Bathroom wall grooves for in-wall electrical conduits	
		Exterior bedroom wall ventilation passage	
		Vertical bathroom duct passages	
		Vertical kitchen duct passages	
		Expansion of the apartment exterior door opening	
	Construction of interior partition walls	Frame installation	Carpenter
		1st side drywall installation	Carpenter
		In-wall electrical installations	Electrician
		In-wall drainage for washing machine	Plumber
		Wall insulation	Carpenter
		2nd side drywall installation	Carpenter
	Vertical drain & floor drain	Vertical drain installation	Plumber
		Fireproofing	Insulation
		Floor drain installation	Plumber
		Floor drain cast	Laborer

The shorter the takt time used in the takt production, the more important precise planning is. In the case project of this study, a takt time of two days was used. It required detailed production planning, as there was only little time to react within the takts. Observations during the implementation of the project showed that the production planning was partly on a level too rough. Respectively, in an apartment renovation study by Lehtovaara et al. [9], the used takt time was one day. According to a survey by Binninger et al. [4], up to 75% of approximately 80 takt production projects had used a takt time of one week. In productions with a takt time of one week, there is more time to react to production disturbances, and hence the significance of detailed forward planning is lesser. In addition, in takt productions with a takt time of one week, every weekend acts as a reserve for overtime work [19], which reduces the importance of detailed forward planning.

Making a comprehensive task list also guides foremen to familiarize themselves with the site and its plans and documents well before production. Making a comprehensive list reveals matters that are unclear with regard to the implementation of the production even before it begins. A comprehensive task list is also of use in subcontracting and logistics planning. When mapping tasks, drying times of materials that require drying are also taken into account, as uncontrollable drying times can easily become a bottleneck that hinders the flow of takt production. These findings support the notion made by Dlouhy et al. [13] that takt production can and should be designed in a high level of detail.

Thoroughly planned takt production simplifies production monitoring and steering. Similar observations have been made also in other projects. According to Alhava et al. [1], steering takt production was difficult on the case site that they observed because there was ambiguity in the definitions of task contents. Thus workers were not sure when a task was acceptably finished, and foremen were not sure when a task could be marked as finished [1]. In addition, on the case site of Andersen and Fyhn [2], the ambiguity of production plans impeded the implementation of takt production. Frandson et al. [5] recommended planning takt production on an adequate level of detail. However, the studies by Alhava et al. [1], Andersen and Fyhn [2], and Frandson et al. [5] did not bring forward what level of detail this meant in practice.

5.2. *Some Tasks Carried Out in Takt Areas May Have to Be Excluded from Takt Production*

This supplement is a challenging one for a few reasons. For once, one could question the validity of removing some tasks from takt areas. If elements are removed from takt production, at which point is it not considered takt production anymore? In practice, if some tasks cannot be carried out as planned, plan deviations happen unless the plan is modified to better accommodate the real situation. In order to make the takt plan followable, some tasks may have to be excluded from it. This already happens in practice, and therefore, it may not be considered novel information. Some mentions of performing certain tasks "off takt" in order to balance the takt schedule exist [15]. However, the mentions are very brief, and therefore, some confusion may be related to excluding tasks from takt production. The following findings supplement what has been written in other literature.

There may be some tasks that can be left out of takt production. Subcontracting, small and expertise requiring tasks, the lack of multi-skilled labor, and the lack of repeatable work complicate takt planning if there is an attempt to include all tasks in the takt production. For example, the progress-based subcontracting model of minor and expertise-requiring work seems to be incompatible with takt production, because slowing down such work to the general production rate is difficult for the subcontractor. On the other hand, cost-plus contracting such quick work can become costly for the main contractor if the subcontractor is obliged to carry out small tasks daily in the spirit of takt production. This provides a counterpoint to the findings of Vatne and Drevland [11] about potentially reducing project costs by switching from piece pay to hourly rates.

If some work cannot be included in the uniform production rate in a way that is reasonable for all parties, and if implementing such work outside the takt production does not impede the progress of the takt production, it is worth considering that work to be excluded from the takt production. In planning the schedule, the requirements and order of tasks as well as time frame available to complete them must be understood. However, an observation was made in the case project that the more drastic and frequent deviations from the planned progress rate were allowed, the more challenging it was to monitor the entire production, as it became less predictable and transparent. Thus, it was more challenging to maintain an overall picture and react to deficiencies. Furthermore, the risk for disturbances may increase if production does not progress as planned.

The waiting caused by simple tasks that are included in the takt production can be reduced with the help of workable backlog, as was pointed out by Frandson et al. [15]. For example, some of the resources in takt production can be allocated tasks from less labor-consuming common spaces or other non-takt areas. Furthermore, material transportation can be used as a workable backlog, as was found in the case project. Nonetheless, it is crucial that the takt production resources must primarily be kept in the takt production, and separate resources must be supplied for production outside of the takt production. There is an appropriate amount of work if the possible disturbance sensitivity of the work has been taken into account in the plan, i.e., the production rate does not fall lower than planned as a result of minor disturbances. This is why Frandson et al. [15] suggested, as an example, reducing workers' utilization to 70–80% of total capacity. Based on references discussing takt production, the approach to takt planning has often been the principle of "all or nothing", where either all tasks in the takt area have been adapted to a uniform production rate or takt production has not been used at all (e.g., [4,5,11]).

5.3. The Tightness and Disturbance Sensitivity of Work Packages must Be Checked after Making the Takt Plan

Based on this study, it is recommended that as part of takt planning, the most disturbance sensitive work packages should be recognized, and possible control measures should be planned together with subcontractors in advance. Foreseeable disturbances must not come as a total surprise to foremen in takt production. This finding adds to the existing takt planning and control literature, since it makes takt control more proactive.

Resulting from the complexity of projects, there are many external factors on a construction site, due to which one cannot expect tasks to always progress at an even rate. Certain tasks include particularly much uncertainty related to their progress in practice. However, in takt production, steady progress is the fundamental idea of the entire production model. To ensure punctuality, the production is planned on the safe side, as needed, by adding buffers into the production. Capacity buffers, i.e., underloading the workers, are recommended as the first option e.g., [10,16], since they allow the work to continue during weakened production rates caused by variation. The second option proposed by Dlouhy et al. [18] is to move most time buffers from the middle of the schedule to the end and to utilize it whenever needed by adjusting the schedule. This is done to minimize waste caused by unnecessary time buffers. If necessary, the takt plan is adjusted after delayed work packages where possible, forming a kind of "catch up plan" [8].

However, this method relies heavily on reactive takt schedule modification, which may be problematic, since reactive takt planning has been a challenge [2,9]. According to Andersen and Fyhn [2] and Lehtovaara et al. [9], takt production requires more proactive production control in order to adhere to takt production and to avoid production control having to constantly react in response to situations rather than proactively controlling them. The experience has been that it is challenging to swiftly plan and implement takt production control measures in case of disturbances during production [2].

In the takt production models by Dlouhy [13] and Frandson [5], the disturbance sensitivity of takt production is reduced by, for example, planning the production together [5] and monitoring and controlling production daily [13]. According to Haghsheno et al. [8], disturbances in takt production are often detected early, and thus, it is also possible to react to them early. However, controlling production based on realized disturbances is reactive.

Based on the case study, a more proactive solution would be to evaluate the time buffers included in each work package and to search for the most volatile work packages in order to remove unnecessary time buffers. Each work package that has been underloaded includes some buffer time [18]. Furthermore, individual empty "time buffer wagons" can be added to the takt schedule [18]. In practice, it is not possible to place a time buffer around every task that is slightly sensitive to disturbances. For example, the possibility of allocating time buffers is typically limited due to a tight overall schedule. In such cases, the foremen must find the most sensitive tasks. If such tasks are disturbed, they have the most significant negative impact on the takt production lead time. Sensitivity analysis such as this can be an estimation; one example is that in Figure 5. Work package specific risks can be evaluated by estimating the probability and impact of each work package specific delay. Based on the literature, this is novel in the context of takt production in general.

	Probability of delay	x	Impact of delay	=	Risk
Work package 1	Small		Large		Medium
Work package 2	Medium		Medium		Medium
Work package 3	Large		Large		Large
Work package 4	Small		Small		Small

Figure 5. An example of a rough risk analysis of the significance of delays of wagons.

5.4. Takted and Non-Takted Tasks must Be Coordinated

Based on this study, takt production and other production must be coordinated. Similarly, according to Frandson and Tommelein [7], the successful implementation of takt production requires the coordination of all parts of the production system. In the takt planning and controlling method described by Dlouhy et al. [13], it is mentioned that clashes can be detected, and dependencies are defined at the macro level of takt planning. However, based on the case project, much clearer instructions are needed to coordinate segments of production, especially if only some segments abide to takt production.

In comprehensive production planning, the coordination of tasks progressing in different directions through work sites must be taken into account. Comprehensive planning must also acknowledge the scheduling of such non-takted tasks that are significant for the progress of the takt production—for example, roofing, stairway, and cellar works. An example of this coordination of non-takt and takt production phases on the case site are roofing works, where the coordination of different tasks in practice meant that the protection of the roofing had to be started before the residents had moved out.

When the entire production takes place as takt production with a common direction, trades collide less, and thus, coordinating tasks is simpler. In practice, it is very hard to fully include a production such as the case site in takt production, which is why the encounters of works progressing in different directions must be taken into account as a part of production planning. Realistic production must be ensured by comparing the planned production dates of takted and non-takted tasks in different work areas. The objective is to find tasks that take place at the same time (on the same day) in the same work area and to plan the order in which they are performed. This was found to be critical in the case project.

In coordinating works, possible concurrent tasks in the same site must be taken into account. For example, building service risers are installed in the ducts of the apartments usually advancing from down up, whereas other tasks in the apartments progress floor to floor from the top down. On the case site, tasks in dry and wet areas had been divided into separate takt production sequences, which is why, for example, the self-leveling and the installation of a new floor surface in the dry areas prevented access to the bathroom. There were similar challenges described in the Lehtovaara et al. [9] study. Realistic scheduling calls for a task collision analysis of different tasks such as the ones mentioned previously. Such task collision analysis seems to be a novel proposition in the context of takt production in general.

The proposed task collision analysis specifies which tasks advancing in different directions are, based on the schedule, to be carried out on the same day in the same apartment. Then, it defines what possible problems these collisions cause for the execution of each of the tasks. Finally, foremen decide on the solutions to these problems in advance. A short takt time requires especially rapid reactions e.g., [2], which is why anticipation is critically important. Figuratively speaking, the foremen act as traffic controllers for two intersecting lines of traffic. Task collision analysis reduces the accumulation of problems that are unexpected and require rapid responses during production.

Based on the case project, making a task collision analysis by hand is laborious. It may be necessary to make the analysis several times if a set or a nearly set schedule is adjusted. Therefore, the task collision analysis should take place automatically based on digitalized schedule data. An automatic task collision analysis should produce information about the unique combinations of tasks taking place in the same place on the same day. This would require the development of software suitable for scheduling takt production.

5.5. Effective Takt Plan Modification during Production

There may be a need to modify the takt schedule during production or between segments. Based on the case project, in order to make justified decisions when modifying the schedule, the modifications must be made together with subcontractors and based on documented actualized task duration data from the site. Then, the modifications are based on the expertise of the site organization.

Digital actualized task duration data that have been systematically collected from the production can be automatically processed into a form that helps production control and schedule adjustments. According to Frandson et al. [5], communicating the production plan to the worker level is the biggest challenge in takt production.

Keeping the worker level up to date requires digital tools, as with the help of such tools gathering production data, analyzing data, and providing information is possible without using a remarkable amount of time. To support production monitoring and control, digital tools should be developed for such projects where the intention is to punctually adhere to the schedule. This is not limited only to takt production projects or renovation. On the case site, a continuous improvement model was developed for takt production by implementing a rough digital production monitoring system, utilizing manual data gathering and automated spreadsheets. However, maintaining a constant situation picture of the worker level was not reached on the case site. Some digital applications may have been used in other projects described in the literature, but such applications have not been mentioned.

Digital systems such as the one described above are not necessarily yet commonly available, but it is recommended that they should be developed for the needs of takt projects. If the intention is to monitor the actualization of production in detail with digital tools during production, it is worth using a detailed task list as described in the first proposed solution as the basis for actualization entries. For automatic actualization data processing to be possible, the takt schedule must also be in a digital format that allows as-planned to as-built data comparison. For this reason, takt planning should also be done digitally. Based on the case site, such programs are not yet available, and for example for the case site, the takt schedule was planned with a spreadsheet program.

6. Limitations

This study has possible limitations. The results of the study are mainly based on the experiences gained from the case project. On the other hand, the project included five nearly identical apartment buildings. This provided the possibility of developing and testing the takt production model in several buildings in a row.

This study was carried out as an action research. One of the main criticisms regarding action research is its subjectivity. Due to the intensive nature of action research, preconceptions about the studied subject may easily arise in the researcher. These preconceptions may affect the analysis of observations.

Another criticism to action research is related to the role of the researcher in the studied organization. The role of the researcher as part of the organization is often such that there may be pressure to misrepresent the results in a way that is positive to the organization. In this study, the role of the main author as a part of the construction site organization was temporary, and hence, there is no pressure to misrepresent the results. In addition, the findings of this study are such that they do not damage the image of people or organizations.

Based on a literary review, there are few articles about takt production in the construction industry in scientific journals. Thus far, publications about takt production in construction have been mainly in the form of conference papers.

7. Conclusions

Based on the findings of this study, successful implementation of the takt production model requires a more active approach starting from production planning. Production plans must be drafted so that they state unambiguously and in detail what is to happen in each work site during each takt. Then, it is possible to notice possible obstacles in time and solve them before production. In addition, the clarity of production plans is a prerequisite for successfully monitoring and controlling production. The beneficiality of planning takt production in detail has been noted in previous research. This study adds to this notion by further clarifying how tasks should be planned in a high level of detail, at least in apartment renovation projects. This has been vaguely described in previous literature.

Excluding some tasks from takt production is discussed in detail in this study. This already happens in practice and therefore might not be novel information. However, excluding tasks from takt production has not been discussed in previous literature, and therefore, this discussion advances the research.

Tasks outside of the takt production must be coordinated when scheduling production. Ignoring the conditions outside of the takt production causes disturbances in its smooth implementation. The conditions of takt production differ from site to site. In this study, coordinating takt and non-takt production is discussed in more detail than in previous takt literature. For coordinating takted tasks and detecting task collisions proactively, task collision analysis is proposed as a novel solution in this study.

Takt production requires rapid reactions. Thus, foremen must be able to anticipate the most common production disturbances. Every disturbance cannot come as a total surprise to them. By doing a disturbance sensitivity consideration, foremen can assess in advance what are the most critical and disturbance sensitive tasks in terms of the schedule. Then, the countermeasures for the disturbances can be planned in advance as well. It is advisable to investigate the uncertainty related to the specified work packages in advance to reduce disturbances in the takt production. Then, work packages can be adjusted, e.g., with buffers to become less sensitive to disturbances. Furthermore, the preparedness for disturbances is better when it is known where disturbances are most likely to appear. Methodologically assessing the tightness and disturbance sensitivity of the takt schedule is novel information.

Based on the study, the time management of foremen is stringent even without the active production control required by the takt time. Thus, an increased use of digital tools that support project management and scheduling during production is recommended to support management. According to the findings from the research site, digitizing the documentation from daily site monitoring can bring significant benefits for the development of management and the production model.

Based on this study, studying the monitoring and controlling of takt production in more detail is recommended as a subject for further research. For this purpose, digital tools for the monitoring of takt production should be developed and their use studied in construction site conditions. Combining digital tools with the proposed detailed task definition and pre-emptive planning, comprehensive production monitoring should be achieved. The time management of foremen is stringent even in a traditional production model. In takt production, the time management of foremen may change slightly, when the emphasis of production management is shifted toward proactivity.

The gathering and documentation of takt production actualization data should be studied. For the development of takt production, more fact-based data should be gathered regarding, for example, the planned and actualized start and finish dates, amounts of resources, and production rates. Useful information could also be gathered of the actualization of workable backlogs, waiting times in work sites (on a daily level), and resource utilization rates (days when the resources were waiting for work sites). The gathered data would also make it possible to compare the effects of the takt production model and the traditional production model. Digital tools should be used for this purpose to avoid overloading the foremen with such tasks.

The impact of implementing takt production into construction projects should be researched in future studies. For example, some promising data exist regarding shortening the project duration with takt production. Defining the impact of takt production may be challenging, since construction projects are often very complex, there is a lot of contingency, and organizations change from project to project. Multi-case studies could be conducted in comparable projects to better evaluate the impact of takt production.

The research was conducted in a renovation project, and therefore, the findings of this study apply at a minimum to similar projects. Adopting takt production in an apartment building renovation project has not been researched in the existing literature before. As far as generic takt production is considered, all of the five main supplements described above are recommended to be taken into account. However, further research should be conducted on the matter in order to acquire evidence for such claim.

Author Contributions: Conceptualization, K.K., A.S. and J.-M.J.; methodology, K.K. and A.S; validation, K.K.; formal analysis, K.K.; investigation, K.K.; data curation, K.K.; writing—original draft preparation, K.K.; writing—review and editing, K.K., A.S. and J.-M.J.; visualization, K.K.; supervision, A.S.; project administration, A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by European Social Fund, Programme for sustainable growth and jobs 2014-2020, EURA 2014/4288/09 02 01 01/2016/HÄMELY (RAKSAVIRTAA Project).

Conflicts of Interest: The authors declare no conflict of interest.

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