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Tetik, Müge; Peltokorpi, Antti; Seppänen, Olli; Leväniemi, Mikko; Holmström, Jan
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Published in:
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT: ASCE

DOI:
[10.1061/\(ASCE\)CO.1943-7862.0001921](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001921)

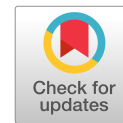
Published: 01/01/2021

Document Version
Publisher's PDF, also known as Version of record

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Please cite the original version:
Tetik, M., Peltokorpi, A., Seppänen, O., Leväniemi, M., & Holmström, J. (2021). Kitting Logistics Solution for Improving On-Site Work Performance in Construction Projects. *JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT: ASCE*, 147(1), [05020020]. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0001921](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001921)

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Kitting Logistics Solution for Improving On-Site Work Performance in Construction Projects

Müge Tetik¹; Antti Peltokorpi²; Olli Seppänen³; Mikko Leväniemi⁴; and Jan Holmström⁵

Abstract: Material kitting has been proposed as an effective solution to organize just-in-time (JIT) material deliveries around assembly tasks; however, its applicability and impact on construction projects has not been thoroughly studied. The purpose of this research is to evaluate the applicability of kitting by focusing on its impact on work performance and requirements for management. The authors conducted a case study to analyze a kitting intervention in a general contractor and logistics company, comparing four renovation projects in the indoor construction phase with and without kitting. Findings indicate that kitting can stabilize assembly work and increase workplace utilization and on-site labor productivity. However, it requires centralized material logistics, smooth information flow between operations, and subcontractors' commitment to the production model. This research contributes to the connection between material logistics and work performance, suggesting that kitting should be linked to a redesign of the general production model toward a synchronized takt-based production system. The research is limited to four projects. DOI: 10.1061/(ASCE)CO.1943-7862.0001921. This work is made available under the terms of the Creative Commons Attribution 4.0 International license, <https://creativecommons.org/licenses/by/4.0/>.

Author keywords: Construction logistics; Material kitting; Assembly kit; Work performance; Renovation projects.

Introduction

In construction projects, various materials and resources come from different suppliers to assemble a complex and unique end-product. This, together with decentralized project organization in which most subcontractors are responsible for purchasing materials they need on-site, makes logistics management at the project level a complex task. Existing research on logistics in construction has suggested multiple solutions for improving material deliveries in projects, including logistic centers (Hamzeh et al. 2007), just-in-time (JIT) deliveries (Arbulu and Ballard 2004; Hamzeh et al. 2007), use of Kanban (Arbulu and Ballard 2004), and safety stocks (Caron et al. 1998). Information technology (IT) tools are recommended for supporting logistic planning and execution, such as building information modeling (BIM) (Said and El-Rayes 2013, 2014; Bortolini et al. 2015), simulation and optimization (Voigtmann and Bargstädt 2010; Said and El-Rayes 2013, 2014), and web-based systems (Elfving et al. 2010; Arbulu et al. 2005). However, the importance of logistics practices is only recently becoming widely recognized in the construction industry.

Recent research has highlighted the role of logistics not only in accurate and effective material deliveries but also in its impact on work performance on-site. Logistic solutions can impact workflow reliability and labor productivity in multiple ways (Seppänen and Peltokorpi 2016). For instance, the optimal buffer size helps to achieve the best performance in operations, such as in the fabrication and installation of steel reinforcements (Horman and Thomas 2005). Logistics is perceived as an extra cost by contractors. Specifically, costs increase when labor has to search for materials on-site, which leads to decreased labor performance (Arbulu and Ballard 2004). Skilled labor usually transports materials from a storage area to the workplace, which leads to wasted effort by the skilled worker, who is more expensive (Elfving et al. 2010); however, the relationship between the material delivery model and assembly work productivity has not gained much attention in the construction management literature.

One effective practice for linking material delivery with assembly operations is called kitting. Kitting is a logistics solution in which parts are supplied to assembly operations in previously sorted kits (Hanson and Medbo 2012). Kitting can increase productivity via the efficient usage of material locations. Kits can be placed close to the location at which they will be consumed. Thus, kitting decreases the time spent searching for parts needed in assembly operations (Hua and Johnson 2010). Kitting can be used in renovation projects, improving the workers' workplace utilization rate (Tetik et al. 2018). With kitting, material availability can be met through high-quality logistics and procurement, which can lead to higher production rates (Tetik et al. 2019). When kits are prepared rather than all materials being delivered in bulk, defective materials can be sorted out earlier on; thus, only the required, undamaged materials are delivered as kits at the right time. Overall, this can improve material quality; however, the existing research on kitting in construction is limited. There is a need for more comprehensive knowledge of the effects of kitting on work performance and management conditions.

The purpose of this research is to evaluate the applicability of material kitting in construction. More specifically, focus is placed on analyzing the impact of kitting on on-site assembly work

¹Doctoral Candidate, School of Engineering, Dept. of Civil Engineering, Aalto Univ., Espoo 00076, Finland (corresponding author). Email: muge.tetik@aalto.fi

²Assistant Professor, School of Engineering, Dept. of Civil Engineering, Aalto Univ., Espoo 00076, Finland. Email: antti.peltokorpi@aalto.fi

³Associate Professor, School of Engineering, Dept. of Civil Engineering, Aalto Univ., Espoo 00076, Finland. ORCID: <https://orcid.org/0000-0002-2008-5924>. Email: olli.seppanen@aalto.fi

⁴Development Coordinator, Fira Oy, Teknobulevardi 3, Vantaa 01530, Finland. Email: mikko.levaniemi@fira.fi

⁵Professor, School of Science, Dept. of Industrial Engineering and Management, Aalto Univ., Espoo 00076, Finland. Email: jan.holmstrom@aalto.fi

Note. This manuscript was submitted on October 28, 2019; approved on May 21, 2020; published online on October 19, 2020. Discussion period open until March 19, 2021; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Construction Engineering and Management*, © ASCE, ISSN 0733-9364.

performance and the requirements for effective kitting sets for the project and its management. Work performance is considered widely, including both its transformation and flow aspects, such as labor productivity and flow of work in locations (Sacks 2016). In the present empirical research, four renovation projects are investigated and compared, two with and two without kitting. For the projects using kitting, the general contractor adopted a kitting approach with the aid of a logistics company, preparing a detailed plan of the work schedule and the materials needed for each apartment prior to the project start with the aim of centralizing the material procurement. The required materials were supplied as apartment-based kits prepared by the consolidation center that the logistics company manages. The specific research questions in the empirical analysis include the following:

- What is the impact of kitting on work performance?
 - Under which conditions does kitting work better than a conventional logistic model?
 - What are the implications of kitting for management?
- The research contributes to the knowledge of material logistics and work performance in construction.

Theoretical Background

Theoretically, this research combines two research streams: (1) assembly work performance problems due to material delivery issues; and (2) kitting as a logistics solution for improving assembly work.

Assembly Work Performance Problems Originating from Material Delivery Issues

Construction projects face challenges due to various factors, one of which is material deliveries. Materials are often either ordered too late, causing suppliers to maintain high supply levels to guarantee the delivery, or too early, causing material buffers on site (Vrijhoef and Koskela 2000). Many studies have shown that productivity and the flow of assembly work in construction have remained low, lagging behind many other industries (Lönngren et al. 2010; Sullivan et al. 2011; Fulford and Standing 2014; Tetik et al. 2019). Thorough studies on workers' daily activities indicate that material delivery is a very significant factor hindering improvements in workflow and productivity (Vrijhoef and Koskela 2000; Abdul Kadir et al. 2005). Misplaced materials and components threaten structural stability, require rework, lead to safety issues, cause delays, and increase costs (Ju et al. 2011). Moreover, material piles can limit worker mobility and cause delays in the delivery of the project. Detailed material delivery schedules and their implementation, storage of the materials on site, and smooth, orderly material flows improve on-site productivity (Banik 1999).

Ordering the right amount of materials at the right time is challenging due to information requirements about material availability and short response times for schedule changes. Information on material availability is required for planning material deliveries and ordering the materials (Ala-Risku and Kärkkäinen 2006). Delay in material delivery has been determined to be one of the major causes of construction project delays (Assaf and Al-Hejji 2006). When a preceding task is delayed due to a material delivery issue, the next task and any succeeding tasks are delayed if the issue is not solved in a timely manner (Vrijhoef and Koskela 2000). Thus, proper logistics planning (i.e., a detailed material delivery schedule) and operations can help to follow a detailed and updated assembly work schedule through timely delivery of materials.

Ensuring that the right materials are delivered to the right installation location is crucial for construction professionals. The success

of a logistics activity depends on making resources available to the next user in the supply chain on time, for which information and resources are essential (Sullivan et al. 2011). Most companies have not yet realized the benefits of logistics practices and supply-chain management (Fadiya et al. 2015); however, timely project delivery and high work performance require material deliveries to be appropriately planned and controlled, which is usually problematic due to the large variety of materials needed in a project and the decentralization of responsibilities among multiple subcontractors who procure, order, and handle the materials themselves. Therefore, kitting centrally procured materials can be a solution for improving construction logistics.

Kitting as a Logistics Solution to Improve Assembly Work Performance

In the manufacturing industry, kitting refers to organizing, packing, and delivering the products or components required for a specific assembly task as one package to the assembly location (Bozer and McGinnis 1992). The kit is a carrier, such as a box or trolley, containing the parts and consumables for a single assembly task (Hanson and Medbo 2012). The parts included in the kits depend on the customer's or product's specifications at each location and may vary between kits of the same assembly task (Limère et al. 2012). Kitting is a commonly used system for implementing in-factory component flow (Hua and Johnson 2010). In construction, product location, such as a building or structure, is typically fixed, with different assembly trades flowing through the product and adding value.

All required parts are placed into the kit in a central picking store (Limère et al. 2012), often called a consolidation center. Through consolidation centers, the materials are kept for a period of time until their delivery to shops or sites on a JIT basis by logistics workers (Sullivan et al. 2011). Logistics centers can be utilized in an efficient manner by expanding the scale of operations (Sundquist et al. 2018). Specifically, logistics centers can be combined with other logistics practices. Hamzeh et al. (2007) stated that logistics centers can be configured for purposes such as assembly, kitting, consolidation, sorting, and breaking materials purchased in bulk.

Assembly kits are typically JIT-delivered to the site so that the materials are installed immediately without being stored at the construction site (Tommelein and Li 1999). JIT delivery decreases the need for an on-site storage area (Jaillon and Poon 2014) and increases the material delivery quality and efficiency (Pheng and Hui 1999). Kit preparation causes extra material handling; thus, on-site work performance should increase to offset these extra costs related to material packaging and kit delivery.

Defining the total costs of kitting is complex due to its indirect effects on labor and material costs. Total costs also depend on the scale of the project and the amount of kitting used. The initial cost for using kitting method includes (1) warehouse rental, cleaning, and equipment; (2) labor costs for picking and packing materials in the consolidation center; (3) planning and scheduling the deliveries; (4) transportation; (5) carrying the kits on-site; and (6) administrative costs such as billing. Literature from manufacturing industry suggests that kitting reduces inventory costs, manpower, paperwork, and purchase order costs (Vujosevic et al. 2012). Third-party logistics providers (TPL) can be used for material handling, which would decrease the total workload of construction workers (Ekeskär and Rudberg 2016). More specifically, Fagerlund (2019) investigated the cost of utilizing consolidation center, which is a part of kitting practice, for a €93 million construction project: the cost of warehouse rent, logistics workers, and equipment in consolidation center would consist of 0.8%–1.44% of the total cost,

whereas transportation to the site would take 0.15%–0.3% and site logistics cost would be 0.8%–1.24% of the total project cost.

Kitting practice can affect work performance in several ways. To determine and operationalize these impacts, the concept of flow is useful. In manufacturing industries, flow is considered the constant movement of a product, namely bringing work to the worker (Sacks 2016). In the construction context, the flow of locations is more visible. According to the Portfolio Process Operation (PPO) model (Korb et al. 2017), improved construction flow entails improvements in project flow, location flow, and trade flow (Sacks 2016). The interdependence of these flows means that location flow (e.g., the flow of consecutive works in one location) can positively affect both project and trade flows. Therefore, the present study investigated work performance in construction in terms of location, operations (trade), and projects perspectives. The workplace utilization rate was used as a metric for the location perspective, with higher utilization rates indicating better workflow at a single location, such as an apartment, namely better product flow. For the operation perspective, the labor productivity of different activities and the share of workers' value-adding time is used to represent trade flow. Similarly, for the project perspective, schedule adherence is used as metric.

Although kitting has been utilized in the manufacturing industry for years, there has been little research on its impact (Hanson and Medbo 2012). Moreover, kitting is not widely used in conventional construction, and little empirical research has been conducted on its applicability or impact (Tetik et al. 2018). Kitting has been mostly used in the manufacturing industry (e.g., Hua and Johnson 2010), especially in the automotive industry (e.g., Limère et al. 2012; Hanson and Medbo 2012; Hanson and Brodin 2013), but Tanskanen et al. (2009) proposed that kitting could be used in the construction industry as well. In summary, there has not been sufficient research into how kitting affects assembly work in the construction industry. Even in the manufacturing industry, kitting has been analyzed primarily from a material logistics perspective, without investigating its impact on assembly work performance. This research aims to address this research gap by considering the overall effects of kitting on construction projects, including its effects on various flows of work performance and its implications on project and management conditions.

Methods

Research Approach and Case Description

The present empirical research aimed to understand the applicability of kitting in construction projects, including both its quantified effects (what) and qualitative conditions for implementation (when/how). To measure its quantified effects, it should be possible to control between kitting and nonkitting conditions in otherwise similar contexts. On the other hand, to identify its qualitative conditions and implications on management, hidden mechanisms affecting the success of kitting in a project context should be thoroughly examined. To meet both of these requirements, a case study approach was chosen: in total, four case projects of a Finnish construction company that was transitioning from a traditional logistic model toward a kitting solution in its renovation projects were analyzed. This approach enabled the collection of data from both kitting and nonkitting projects, following the idea of a comparative case-study design (Yin 2014). It helped collect in-depth data on the experiences of the individuals' involved in the projects and their opinions regarding kitting implementation.

The company's overall aim was to use lean and industrialization methods to remove external variation and improve performance in

its renovation projects. They hired a logistics service company as a partner to implement kitting that had previously been used in the Finnish shipyard industry. The contractor used a combination of centralized material procurement, material packaging to kits in the consolidation center, and JIT delivery of the kits to site in its renovation projects. In total, four case projects were investigated, two using the kitting solution and two not using kitting, meaning that their materials were purchased and ordered by different trade contractors and stored on-site without strictly coordinated rules regarding their handling. The selected case projects were otherwise similar to one another in terms of the scope of the renovation work with a similar location, project size, and structure type of the building.

To provide more context, the empirical analysis focused on the bathroom renovation activities in the selected case projects. Most of the bathroom renovation activities, such as pipe branching, tiling, ceiling, and fixtures, represent indoor construction tasks that are rather similar in any building project, not only renovations. Moreover, projects with bathroom renovation activities operate under high pressure to shorten the amount of time inhabitants cannot enter their apartments (Alhava et al. 2015). Reliably shortening project time is challenging because surprises in demolition work and apartment-specific customized requirements make the planning and control of work and material flow a difficult task for the contractor. Thus, utilizing kitting logistics solutions could help overcome these difficulties.

Data Collection and Analysis

As focus of this empirical research is on the impact of kitting on on-site work performance, four operational and time-related measures were selected to guide the data collection and analysis. Other aspects not directly connected to work performance, such as cost, safety, or material waste, were not primarily considered. Following Sacks (2016)'s idea of project, product, and trade flows, the four selected performance aspects included (1) stabilized assembly work, which was measured by schedule compliance (i.e., how well assembly work followed the plan); (2) product flow, which was measured by the share of value-adding time in one bathroom per day; (3) labor productivity, (i.e., at the single assembly task level, how much of a worker's time was used on each task); and (4) trade flow (i.e., share of value-adding time per worker).

To investigate these multiple aspects, multiple data collection methods were required. For example, analyzing product flow requires collecting data on all activities taking place in one bathroom. On the other hand, analyzing trade flow requires following up a single worker's workflow in multiple locations during a day. It was found that using all methods on a single project would be too laborious for site management. Therefore, to decrease burden of measurement arrangements in one project, in total four case projects forming two project pairs were selected. In both pairs, only some of the aspects were analyzed. Table 1 illustrates the selected projects, their logistic solutions, the work performance aspects analyzed, and the primary data sources. Of the four cases, the authors conducted two separate comparative case studies. In all projects, the workers were informed that the observation was not to evaluate a particular worker and that the results will not affect their work contracts or be shown to their managers. The identities of the workers were unknown to the researchers.

For the projects, the authors collected both qualitative and quantitative data for data triangulation (Ketokivi and Choi 2014). Data triangulation is required to test the validity of the work through the convergence of information from different sources (Carter et al. 2014). The qualitative component of the research was carried

Table 1. Research design of the case projects

Project	Logistics solution	Analyzed work performance aspects	Data collection methods and amount of data
Project 1: residential, 16 flats	Centralized material procurement, material packaging to kits in the consolidation center, JIT delivery of the kits to site	Daily workplace utilization rate Schedule compliance	Camera-based video recordings in bathroom (32 work shifts in 32 days) Two site visits and three interviews were conducted with a project manager and site supervisor. Observations in the consolidation center.
Project 2: residential, 9 flats	Traditional	Daily workplace utilization rate	Camera-based video recordings in bathroom (24 work shifts in 12 days)
Project 3: residential, 96 flats	Centralized material procurement, material packaging to kits in the consolidation center, JIT delivery of the kits to site	On-site assembly work productivity Share of value-adding time per worker	Researcher observing assembly and logistics activities (14 working days) Branching: 3 days Tiling: 3 days Ceiling: 2 days Fixtures: 2 days Site logistics: 2 days Consolidation center 2 days Site manager, workers of the observed tasks, and the manager of the consolidation center were interviewed.
Project 4: residential, 216 flats	Traditional	On-site assembly work productivity Share of value-adding time per worker	Researcher observing activities of assembly workers (11 working days) Branching: 4 days Tiling: 4 days Ceiling: 1 day Fixtures: 1 day Site logistics: 1 day Site manager and workers of the observed tasks were interviewed.

out using interviews and empirical observations, and the quantitative component was carried out as a comparative case study of the projects. Data for this comparison was obtained by monitoring the workers (with a follow-up on-site) and measuring the time used for different tasks, specifically measured with a stopwatch and camera-based method. Moreover, document analysis was used to determine schedule compliance. Table 1 presents the amount of time used to collect the data and the data collection method. The video recordings did not always make it possible to analyze the task contents accurately; therefore, human observation was used in the other two projects.

In Projects 1 and 2, the analysis focused on the product flow, measuring daily workplace utilization rates in bathrooms. Trucco and Kaka (2004) mentioned a framework that uses a camera to track the on-site progress of tasks. Gong and Caldas (2009) presented a computer vision-based model for interpreting the videos from construction operations into productivity data. Following these ideas, the contractor company placed cameras in one bathroom in both Projects 1 and 2 (Fig. 1). To obtain information for performance measurement, the cameras took photos when any movement was detected in the bathroom.

Based on the video recordings, the authors were able to identify the time periods when a worker was present in the bathroom and whether the activity was value-adding or not. Zhao et al. (2019) analyzed labor productivity based on the uninterrupted presence of the worker in the work location. The collected data included different durations of several types of work during the presence of the worker. Breaks, phone time, and walking around were categorized as non-value-adding. Clear work activities and unavoidable waiting time, such as waiting for waterproofing to dry, were considered value-adding. Fig. 2 illustrates how the value-adding time was defined. The sum of the T_n durations gives the total value-adding time duration for that day. Workplace utilization rates were calculated

for each working day by dividing the daily total value-adding time at the work location by the time difference between the start of the first and end of the last working time period of the day.

A high utilization rate indicates the better product flow of a single apartment (Sacks 2016). Thus, to have a high utilization rate, worker's nonattendance and non-value-adding time should be minimized because it means that the worker spends less time seeking, collecting, and transferring materials outside the apartment. However, the ability to capture planning or other work-related supporting activities conducted outside the bathroom was limited and thus excluded from the analyses. It was also not possible to place the camera inside the bathroom because it would interfere with the work done in the bathroom. Therefore, fixed camera position outside the bathroom was used (Fig. 1). As a result, it was impossible to reliably identify all conducted tasks in the bathroom. Therefore, task-level productivity was not analyzed based on the camera recordings, but that aspect was analyzed in Projects 3 and 4.

To analyze schedule compliance in Project 1, document analysis was conducted to compare the planned work schedule with the actual kit delivery dates in the apartments where the camera was placed. The work tasks were determined by observing the camera-documented bathrooms and then comparing observations with the planned work schedule and kit delivery schedule. Moreover, the authors observed both the work sites and the consolidation center. They also interviewed the project manager, site supervisor, and operations manager of the logistics provider about the design of the logistics solution and their experiences with production planning, material kit preparation, delivery, and on-site installations.

In Projects 3 and 4, focus was placed on labor productivity, defined as the required work time per assembly task and the share of value-adding time per worker. The primary data collection method involved observing assembly workers. One of the authors followed the workers from a distance so as not to distract them during their



Fig. 1. Camera angle from Project 1.

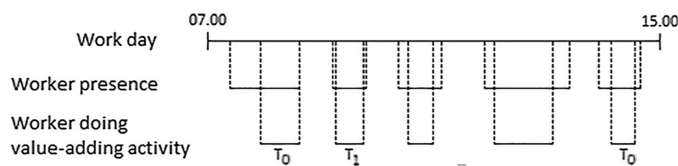


Fig. 2. Calculation of value-adding time duration.

work and registered all their tasks and their durations. It was impossible in this case to use static camera-based measurement to register value-adding activities of the moving workers. However, a human observer enabled the evaluation of work productivity when video recordings are not sufficiently accurate for identifying the task in progress due to the static position of the camera. Value-adding time was calculated using the same method as in Projects 1 and 2.

In Projects 3 and 4, four different but common work tasks were studied: (1) branching of sewer and water supply systems; (2) tiling; (3) ceiling; and (4) fixtures. The branching task included cutting the pipes, attaching the connectors, and installing the supporting rails and clamps. It was included in the study because it involves a variety of parts and thus the advantage of kitting is rather obvious. The tiling task included waterproofing, floor and wall tiling, and seaming. It was included in the study because it involves a customized selection of tiles, requiring kitting to support a variety of different tile types delivered with apartment-specific kits. The ceiling task included constructing the framework for the ceiling and the ceiling itself. Ceiling work was included in this study because it is difficult to handle the large parts required for renovating the ceiling; therefore, specialized logistics can aid in moving the materials to the work location, affecting the productivity of the work.

Fixtures included installing fixtures, such as hand basins and basin closets, bathroom cabinets, shower curtain rails or shower glasses, and towel hooks, among others. This task was included in the research due to its large number of large parts that were difficult to move between locations. Not all the workers agreed to be followed while working, so only these four work tasks were observed.

The labor productivity differences in each work task between Projects 3 and 4 were analyzed. The productivity of work can be defined as the ratio between the output of the process and the applied labor input (Sumanth 1998). In this study, the output was constant (a completed task in the bathroom), and the input was measured based on observation data. To calculate labor productivity, the average working times per bathroom per task were used as an input. Moreover, the number of different activities was measured to identify the number of interruptions to work.

Because the data set was relatively small (1–4 days per task per project), the effects of random factors on the results might be large. To reduce randomness in the activities, value-adding time was calculated by removing personal time, breaks, other work, and undefined activities from the analysis. Similar research was conducted by Josephson and Saukkoriipi (2007), in which the time was similarly analyzed through its categorization into direct value-adding time, preparation, and pure waste. The same activities were included and excluded from the total value-adding time of all the projects. For instance, breaks, chatting, talking/being on the phone, and finding and moving materials and tools to the workplace were excluded from every task and project being calculated for value-adding time. Value-adding time included activities such as cutting/bending material, measuring, drilling, taking notes, and mixing mortar, namely the value-adding and supporting activities in the work location.

Bathroom size varied between Projects 3 and 4. For Project 3 (2.2, 3, and 2.26 m²) and for Project 4 (2.66 and 2.77 m²). However, the content of all bathrooms was the same during the branching work phase: a toilet seat (sewer and water supply), a hand basin (sewer and water supply), a shower (water supply), a towel radiator (hot water circulation), floor drain (sewer), and washing machine connections (water supply and sewer outlet). The tiling work included waterproofing, floor tiling, wall tiling, seaming, and placing silicone. Ceiling work included gypsum board ceiling installation. In Project 4, mostly wooden panels were used, although some customers preferred gypsum boards. Panel ceilings do not take as much time to install compared with gypsum board, but both methods include carrying materials to the apartment and cutting material outside the bathroom, so hence their work content was similar. The kit, including the ceiling material, also included all plumbing and electrical fixtures. Collecting plumbing and electrical fixtures takes the longest time at the consolidation center. Fixture installation included installing the hand basin and basin closet, bathroom cabinet, shower wall, towel hooks, toilet paper holder, and the inspection cover into the ceiling.

Similar to the first comparative study, project managers, site supervisors, and operations managers of the logistics provider of Projects 3 and 4 were interviewed to collect information about the design of the logistics solution and experiences with production planning, material kit preparation, delivery, and on-site installations.

Kitting Solution in the Case Projects

The new kitting solution was utilized in Projects 1 and 3, meaning that most of the materials were delivered to the site as location- and task-based kits. The kits arrived every day before noon, with the logistics contractor unloading the truck. After unloading, any empty containers, pallets, and surplus material were loaded back

into the truck. The logistics team carried the kits to the floors, typically during the lunch breaks of the other workers to gain better access to the lifts. When there were no kits to deliver, they emptied the trash and surplus material from the apartments. The logistics team consisted of 1–3 workers, and kits were typically pallets wrapped in plastic foil. Small parts, such as valves, plumbing parts, and towel hooks, were stored in 50-L plastic containers. Bigger components, such as tiles, shower fixtures, toilet seats, and basins, were wrapped in these plastic containers. Materials that did not fit on the pallet, such as pipes, shower cubicles, gypsum boards, and metal rails, were marked and carried to the apartments without being kitted. Materials purchased in bulk, such as bolts, were not included in the kits. Surplus kit materials were either forwarded to the next apartment with required updates made to the consolidation center regarding the next kits to be sent to the site or they were sent back to the center along with any damaged goods. In the instances of short kitting, emergency deliveries were made.

The consolidation center used in this study allowed for preassembly of some parts in addition to being a consolidation center. Typically, there were 1–2 workers in the center, and the same individuals performed all the required tasks: receiving the goods, shelving, printing the lists of materials for the kits, placing the required goods into the kits, possibly preassembling some parts, packing the kits, marking the kits by apartment number, and dispatching them.

For Projects 2 and 4, traditional logistics were used, which involved no kitting or consolidation center. Some subcontractors procured and handled their own materials on-site (e.g., plumbing and carpentry). For other contractors, material procurement and handling was performed by the main contractor. In this case, logistics workers employed by the main contractor delivered the materials procured by the contractor to the apartments. In Projects 2 and 4, there were containers used as small site storage areas where small parts such as bolts and some equipment were kept.

Analysis and Results

The interviews indicated that the overall experience of the actors with the kitting logistics solution was positive in terms of work time of the workers compared with the projects using traditional logistics. Thus, the contractor plans to continue using the practice in its future projects with its partnering logistics service provider. Respondents mentioned that the solution saved workers' time because they could perform the tasks they were hired for instead of searching for materials. Even if the costs were not analyzed thoroughly, the interviews indicate that there was no cost difference between Projects 1 and 2.

Impact of Kitting on the Workplace Utilization Rate

Daily utilization rates for case Projects 1 and 2 are shown in Fig. 3. The average daily workplace utilization rate for Project 1 was 38.5%, whereas it was 31.5% for Project 2. Because a higher workplace utilization rate suggests better product flow, the logistics solution seemed to improve the product flow, although it could be partly due to random variation. Project 1 was planned to be completed in 2 weeks; however, it took longer due to customer requirements that were decided after renovation work started.

Fig. 4 shows the distribution of the standard deviations of the projects. Standard deviation distribution for Project 1 is rather between around 30%–50% whereas it is rather between around 20%–40% for Project 2. Thus, it can be said that the practice may stabilize and improve workplace utilization rates. The standard deviation of the workplace utilization rate for Project 1 was 14.3%,

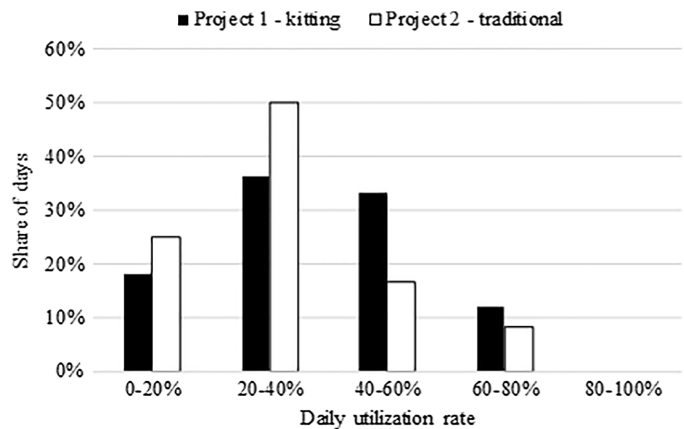


Fig. 3. Distribution of daily workplace utilization rates for Projects 1 and 2.

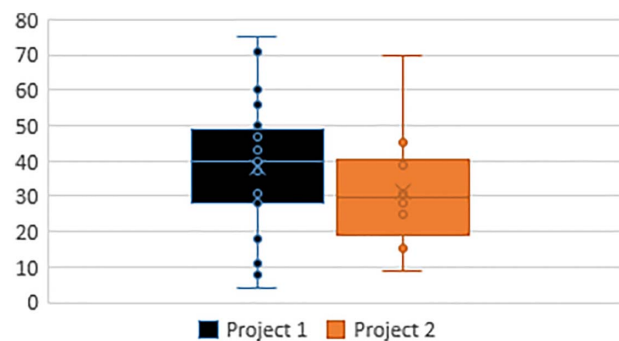


Fig. 4. Distribution of standard deviations of daily workplace utilization rates for Projects 1 and 2.

whereas it was 15.5% for Project 2. This indicates that kitting may not only increase but also smooth out the daily work flow in locations.

Impact of Kitting on Assembly Work Productivity

In Projects 3 and 4, branching, tiling, ceiling, and fixtures tasks in the bathrooms were observed. The activities considered value-adding included necessary work outside the bathroom, treating material outside the bathroom, and value-adding time spent inside the bathroom. The category of treating material outside the bathroom includes mainly cutting and forming materials, such as pipes, tiles, gypsum boards, and wooden panels, and dismantling and assembling fixtures. When the worker was getting the required items, the time was counted as fetching materials/tools/both materials and tools, according to the items fetched. Non-value-adding activities might have been conducted in the bathroom; however, the observer might have distracted the worker by trying to observe these activities inside the bathroom. Because the work phases were different from each other, the results were relative to the work content. Furthermore, only one observer observed the work phases of the projects; due to this limitation, the number of observed bathrooms ranged between two and three per task.

Because kitting generated extra material handling to collect kits, the impact of the consolidation center was observed in Projects 3 and 4. Logistics workers collected the materials for the kits in series. If there were several kits of the same kit number (similar contents), they were collected at once. This reduced the amount

of time spent walking because a greater amount of material could be collected from one shelf at once. Due to collecting style, exact times for individual kit collections were impossible to measure. Thus, amount of time required to collect all the kits each day (typically four to five kits) was measured. After this, the average time spent collecting one kit was calculated. Unlike the on-site measurement, here different types of time (i.e., moving, waiting, and personal time, among others) were not measured separately, and only the collection and handling time of the kits was measured. Tasks such as receiving the material, shelving, and stocktaking were not considered because they would occur without the logistics solution.

Table 2 displays the average branching time for one bathroom in Projects 3 and 4. The amount of time required to complete the task was considerably longer in Project 4 (without the logistics solution) for most activities. In terms of labor productivity, considering the total time for which output work was the same for each project, the input of Project 4 was around 1.89 times that of Project 3 with kitting. Thus, it can be concluded that assembly kitting has a major potential during the branching phase. Moreover, the value-adding time required to complete branching in a bathroom was 123% greater when traditional logistics were used, indicating that many necessary but not core assembly activities could be minimized by the kitting solution. Even when the kit collection and on-site delivery times were considered, the project with kitting showed better completion time for a task in a bathroom.

On the other hand, from the worker point of view, the share of value-adding time of the total work time was lower with kitting, indicating that saved time from material handling was not effectively utilized in value-adding activities elsewhere. Proportionate to the total time, the time spent on fetching materials was higher in Project 3 than in Project 4. Based on the observations, this time was spent on fetching fasteners or pipe-holding clamps that were

not included in the kits. Thus, the effectiveness of the kitting practice could be improved by planning the contents of the kits well. The number of different activities (e.g., how often the worker left the bathroom) indicates there were fewer interruptions to the value-adding work when kitting was used. The working manners of the workers were similar. Thus, the value-adding activities were more continuous in Project 3.

Table 3 presents the average time spent on tiling activities for one bathroom in Projects 3 and 4. For tiling tasks, Project 4 required 13% more time than Project 3. Assembly kitting was associated with a reduced need for value-adding time and time spent fetching the materials and tools. This saved time for the overall project. Furthermore, the number of different activities was lower in Project 3, which indicates fewer interruptions to the value-adding activities. On the other hand, on-site delivery of tiling kits took quite a long time. Therefore, when kit collection and on-site delivery were taken into account, the traditional solution was only 6% less productive than the project with kitting.

Average time spent on ceiling activities is presented in Table 4. Project 4 took 3% more time than Project 3 in terms of value-adding time. The results indicate that assembly kitting has a small, positive effect on the worker's value-adding time, which could be due to random variation. The most significant improvement is in the time spent fetching materials. If kit collection time is considered, the traditional solution seemed to be more productive. The number of different activities ended up being almost the same for both projects.

During the data collection and analysis, it was found that data obtained from fixtures was not reliable for calculating labor productivity. In Project 3, fixture installation was running late and the handover was approaching. Because of the risk that observation might affect the production, the site management prohibited measuring in the same staircase where all the other measurements had

Table 2. Average branching activity time and kit preparation for one bathroom in Projects 3 and 4

Variable	Project 3 (kitting)	Project 4 (traditional)	Difference (traditional/kitting)
Number of different activities	220	254	+15%
Total time	4:32:40	8:34:40	+89%
Time spent in bathroom	1:14:56	3:40:38	+194%
Treating materials outside the bathroom	0:21:01	0:22:56	+9%
Fetching material	0:19:09	0:40:58	+114%
Fetching materials and tools	0:06:07	0:02:28	-60%
Kit collection time in consolidation center	0:36:30	—	—
On-site kit delivery duration	0:08:25	—	—
Value-adding time	2:12:56	4:56:10	+123%
Value-adding share of time	48.8%	57.5%	+18%

Note: Number of bathrooms observed were 3 in each project.

Table 3. Average tiling activity time and kit preparation for one bathroom in Projects 3 and 4

Variable	Project 3 (kitting)	Project 4 (traditional)	Difference (traditional/kitting)
Number of different activities	234	303	+29%
Total time	6:23:00	7:11:00	+13%
Time spent in bathroom	4:24:33	4:30:48	+2%
Treating materials outside the bathroom	0:38:55	0:42:38	+10%
Fetching material	0:23:41	0:25:09	+6%
Fetching materials and tools	0:01:44	0:07:16	+319%
Kit collection time in consolidation center	0:05:36	—	—
On-site kit delivery duration	0:19:15	—	—
Value-adding time	6:00:11	6:19:38	+5%
Value-adding share of time	94.0%	88.1%	-6%

Note: Number of bathrooms observed were 2 in each project.

Table 4. Average ceiling activity time and kit preparation for one bathroom in Projects 3 and 4

Variable	Project 3 (kitting)	Project 4 (traditional)	Difference (traditional/kitting)
Number of different activities	181	180	−1%
Total time	3:51:38	3:52:00	+0%
Time spent in bathroom	1:48:05	1:41:40	−6%
Treating materials outside the bathroom	0:37:20	0:33:01	−12%
Fetching material	0:12:25	0:24:08	+94%
Fetching materials and tools	0:00:00	0:00:54	N/A
Kit collection time in consolidation center	0:38:30	—	—
On-site kit delivery duration	0:09:46	—	—
Value-adding time	2:51:49	2:56:25	+3%
Value-adding share of time	74.2%	76.0%	+3%

Note: Number of bathrooms observed were 2 in each project.

been performed. In Project 4, there was a logistics worker who took care of deliveries handled by the main contractor and was responsible for material waste management. If there were no deliveries arriving, he helped carry the materials to the floors. After the habituation period, when the measuring of fixtures in the project started, it appeared that the goods were brought into the apartments but it was not clear who had brought them. Thus, no data were obtained about the material logistics in the fixture installation phase. Because material logistics were approximately the same for both projects due to fixtures requiring large parts, such as shower glasses, that cannot fit into the kits and must be delivered separately, the difference due to material logistics could not be reliably measured and might be related to working manners of the workers. However, it was possible to observe the trade flow, or the ways in which workers added value to their work throughout the day. This analysis revealed that the share of value-adding activities was 83.5% in the project with kitting and 76.3% in with the traditional logistics.

In summary, the analysis revealed that in most cases, kitting improved workers' productivity but when logistic activities were taken into account, the productivity gain was remarkably narrowed. The kitting practice reduced the amount of steps required for the specialized, on-site workers to install parts. The practice did not require additional workers from the contractor company. However, kitting increased the amount of time required to prepare the kits. In branching (Table 2), Project 3 with kitting solution still produced better productivity than Project 4 without kitting. For the other work tasks, only the on-site productivity was improved rather than total productivity. Interviews and observations indicated that the speed of kit collection was affected by the poor Wi-Fi network the computers that the collectors used. Due to this, workers collected the materials based on paper lists made by the general contractor, marking those collected in a computer after the kit was collected. Interviews with these workers made it clear that the non-optimal information process was a major reason for the slow speed of kit collection; they thought it was pointless and time-consuming.

Implications of Kitting on the Project and Management Conditions

Interviews revealed that the workers think assembly kitting facilitated their work. The kits were brought to the task location, and based on the workers' experiences, having the required materials physically closer to the task location allowed them to more rapidly complete their work because they were able to focus on their own tasks. The plumber in Project 3 stated that much less time and effort was spent on searching for small parts and accessories. In Project 3, tilers did not see much difference between traditional logistics and kitting based on their previous experience because the tiles are

delivered apartment in any case. The ceiling installer was also indifferent to the solution due to the material required: fasteners can be carried in a pocket and gypsum boards can be cut on location in any case. The fixture installers found the practice beneficial because the time spent searching for the right materials decreased. Moreover, if the worker carried the fixtures and shower glasses separately (not as a kit), there would be other workers in his way and he would need to be careful not to scratch the items. When many apartments' fixtures are delivered to the task location all at once, workers only had to make their way on the staircase once.

It was found that kitting would result in more productivity improvements if the subcontractors did not choose to procure and handle their own materials. Each subcontractor has its own maturity level in terms of material and information handling. Centralized procurement of the materials could make it easier to kit every material at the consolidation center and deliver kits to the site in a coordinated manner. Thus, the commitment of the subcontractors to the new logistics system is required.

The assembly kitting practice increased the responsibility of the management because it requires more planning to ensure timely and complete kit deliveries. In Project 3, the solution was regarded with suspicion by the management because it was found to be work-demanding and stressful given that the management had to make the material orders for kits 2 weeks prior to the assembly. Thus, a detailed work schedule had to be available in advance and updated during the project.

Based on the interviews, forecasting assembly schedule during the project was difficult in Project 1. There were challenges regarding the plumbing material delivery, with management reacting to the problem late. Thus, not all the materials were delivered through the consolidation center, and some subcontractors chose to deliver their own materials. The HVAC materials were not ordered by a worker but a manager, which afterward caused the required material list to change. The operations manager of the consolidation center stated that the problems were due to leadership and planning issues.

Materials listed in the bill of material (BOM) were identified and classified based on their area of use in Project 1. The actual work schedule was derived by analyzing the video footage and the BOM, comparing them with the actual delivery dates of the material kits. With the availability of detailed information on the deliveries and BOM, integrating this information earlier in the planning phase would improve control over the subsequent operations. Generating an accurate BOM requires effort from the general contractor as well as the responsible contractors who are to purchase any materials. Generating an accurate BOM facilitates the kitting solution because information about the kit ingredients and delivery times are available.

Table 5. Planned schedule, actual material delivery dates, and tasks detected via the video recordings in Project 1

Data	Dates						
	Monday October 23, 2017	Tuesday October 24, 2017	Wednesday October 25, 2017	Thursday October 26, 2017	Friday October 27, 2017	Monday October 30, 2017	Tuesday October 31, 2017
Planned schedule	Demolition	Empty	Plumber 1	Carpenter 1 and 2	Floor casting 1	Floor casting 1, Electrician 1	Floor casting 1
Actual schedule	Carpenter 1 and 2	Plumber 1	Floor casting	Floor casting 1	Tiler 1	Floor casting 1, no electrician	Floor casting 1
Materials of the delivered kits	Copper pipes, suction pipe branch, connection clamps, mounting brackets	Plaster boards, seam foam, grout, installation materials	Floor casting, electricity materials, primer, foam, draught board, reinforcing mesh	No kit delivery for this apartment	No kit delivery for this apartment	No kit delivery for this apartment	Floor and wall tiles, water proofing materials

The analysis of schedule compliance in Project 1 with kitting showed that the planned schedule roughly matched the actual schedule. Table 5 illustrates an excerpt from the planned schedule of the apartment where the video camera was installed, located over the second staircase in Project 1. There was no major gap between the actual kit delivery dates, and the planned work schedule using the kits were used. For instance, on the first Monday, materials such as mounting brackets and copper pipes were delivered via kits to the apartment based on the actual delivery schedule. Then, 2 days after this delivery, video material showed the plumber working in the bathroom. In most cases, there were a few days between kit delivery and the relevant work in the bathroom. Because there was only one camera with a fixed angle, it was not possible to detect every task performed in the bathroom. The project manager mentioned that during the planning of this project, performance was negatively affected due to focusing more on resource efficiency instead of flow efficiency, emphasizing the importance of planning.

Due to the customer-specific requirements made after the start of the project in Project 1, the rest of the planned schedule was not followed, and completion of the bathroom was delayed by 2 weeks. Tasks detected in November occurred in the following order: wall insulation, plumbing insulation, tiling of the walls, additional wall building, painting the walls, ceiling installation, installing the radiator, ceiling installation, installing other fixtures (lavatory, shower cabin, and towel hooks), installing electricity cables, painting, and installing the electricity cabinet.

The general contractor indicated that there was no significant difference in overall project costs between utilizing kitting practice along with JIT delivery and consolidation center versus traditional logistics. Although the authors could not obtain specific cost data, this general contractor's statement was noteworthy because there is always some initial cost for using kitting, such as collecting the kits and delivering them to the site. The analysis revealed that in two of the three investigated tasks, the labor needed for collecting and delivering kits were offset by the productivity improvement in the assembly task. In addition, if logistics worker's wage is assumed to be around 50% of specialized assembly worker's wage, the direct labor cost savings from the three investigated tasks were on average 19.6%. This analysis does not include additional warehouse, equipment, and management costs. However, if these costs are not typically higher than 3% of the total project costs (Fagerlund 2019), and around 50% of the project costs are typically labor costs to which the kitting can impact, it could be concluded that direct labor cost savings identified in this study would with high probability offset the initial costs of the kitting method. The projects with kitting were learning projects for the general contractor, so more

benefits could be obtained with the practice in the future projects when the practice gets more mature with time.

Conclusions

Discussion

This research investigated kitting as a logistics solution in construction projects. The findings showed that the kitting solution can bring workflow and productivity benefits in on-site assembly activities under certain conditions, such as having a detailed and updated schedule and accurate BOM for each assembly task. More precisely, the findings indicate that assembly kitting improved labor productivity during certain work phases of renovation projects. The findings are in agreement with the existing literature, which indicates that factors related to material management can impact labor productivity and the efficiency of construction (Pheng and Chuan 2006). The biggest improvement was observed in the branching task. Thus, the improvement in labor productivity was greatest for the tasks requiring many small accessories. Large fixtures were not kitted and delivered directly to the site. This indicates that kitting may not be as suitable for the project phases requiring a large number of large materials.

Kit delivery was found to more greatly enforce the planned work schedule. A rough match between the initial planned schedule and the actual schedule brings opportunities such as adopting kitting when implementing takt production (Frandsen et al. 2013). Even though there is a specified schedule available, it is not typically thoroughly followed or enforced (Sarshar et al. 2000). Senior (1996) suggested that contractors are aware of the long-term or immediate tasks that can be conducted if there are materials available. To avoid unplanned activities, only the required materials should be available at the right time. In summary, kitting can help managers to control assembly activities via coordinated material deliveries.

Based on this empirical study, kitting can be applied in renovation projects where delivering the materials in the exact location of use is required and possible. The solution can also be utilized in other types of projects. For instance, the tiles are usually delivered as location-based packages. Tasks in the bathroom renovation project are more similar than in any indoor construction phase of building projects, but nonetheless the solution can also be utilized in the indoor construction phase of building construction projects where there are repetitive tasks. According to Tanskanen et al. (2009) kitting with JIT delivery can be extensively used when there is no inventory at the site. Hamzeh et al. (2007) mentioned that

made-to-order materials can be kitted in logistics centers for engineer-to-order products to produce assembly packages. The practice has been used in the manufacturing and prefabricated house production industries. In the research consortium of which the authors are part along with 18 companies, only a few of them have experience with kitting solutions. However, findings indicate that there is a potential to apply kitting in most of the building projects, especially in the indoor construction phase with lack of inventory space, multiple small accessories, and challenges in coordinating work in different locations.

The research contributes to existing knowledge on material logistics and work performance in construction in two ways. First, the study highlights the connection between material logistics and work performance, identifying opportunities for increasing product flow, trade flow, and productivity in on-site assembly activities through material kitting solutions. Value-adding activities must be made more efficient and non-value-adding activities must be reduced or eliminated (Alarcón 1997). Even if the findings were partially mixed, in general, task- and location-based kitting was found to decrease the overall completion time of the tasks from a worker point of view and to increase the share of value-adding activities in locations. In addition, the study suggests that there is a potential to improve project schedules via kitting. The material deliveries in the present study were made using JIT, meaning that there were no materials available before their planned usage date and therefore the planned schedule was roughly followed.

Second, the study highlights the importance of early, detailed, and updated planning in kitting solutions. Incorporating a complete and detailed plan early in the design phase leads to monitoring work and material flows. Through detailed planning, materials and kit consumption locations were determined early on. Because the workers did not have to search for the materials needed for assembly tasks, the practice led to less material handling by each specialized worker. Pheng and Chuan (2006) stated that materials not being stored close to the work area can cause double handling. A study suggested that installation time was reduced by 140 min when the windows were packed based on which apartment they were to be installed in (Kalsas 2010). Kitting enhances the logical placement of materials so that workers travel less to collect them (Brynzer and Johansson 1995).

The present findings are partially in agreement with the literature: the logically placed kits increased labor productivity in the work phases that require a high number of small accessories. Moreover, the solution generated positive feedback from the workers. Workers and managers perceived the logistics solution as improving workflow, labor productivity, and schedule compliance, and being neutral in costs; however, it increased the responsibility of the management because detailed material delivery planning and schedules are required. The findings contribute to the literature regarding the relationship between material delivery and assembly work in terms of labor productivity.

This study used both video recording and human observation to collect data on site. It was found that utilizing video recording for data collection and analysis helped to measure product flow in fixed locations. On the other hand, a human observer was able to focus on the flow of the workers and tasks. With the diversity of the method used and types of data, the authors provided different kinds of measurement and contributed to the methodology alternatives of measuring productivity.

Limitations and Future Research

The research was limited to focusing on only one type of project and investigating only four case projects; thus, the kitting

application and findings may be context-specific. In addition, even if the cost analysis indicated that benefits of kitting would offset its initial costs, the analysis was approximate because authors could not obtain task-specific cost data from the companies because it was confidential information. Future research should compare the different assembly kit strategies of several projects and analyze not only work performance but also other aspects, such as safety, direct and indirect costs, sustainability, and dwell times of the kits. For example, whether the prepared kits were fully consumed on-site could further enhance the understanding of the impact of kitting on waste.

The results were indicative of the theoretical benefits of kitting, and more controlled experiments should be conducted. During the study, different data collection methods were used for different projects because it was not possible to analyze all aspects in all projects. Future research should invest in more comprehensive data collection strategies in which multiple methods could be simultaneously utilized in single projects. Also, new data collection methods, such as use of helmet cameras, could be considered. In summary, further research should analyze different project contexts and take a more longitudinal approach to develop a kitting solution as well as focus on different aspects that the kitting practice would impact on a construction project.

Conclusions

In this paper, the authors investigated how assembly kitting, using a consolidation center to prepare kits and JIT delivery of kits to site, influences work performance in construction projects. Comparative analysis of four projects showed that assembly kitting can help to stabilize assembly work in renovation projects in which a combination of logistics practices are adopted. Kitting also improved product flow during specific work phases requiring a variety of small parts. Improvements in workplace utilization and work productivity were measured by changes in the value-adding time per bathroom and task. On the other hand, kitting corresponded to lower productivity during some work phases, indicating that it may be less suitable for larger parts. This study contributed to research on how assembly kitting could be a suitable solution for improving work performance in renovation projects and provided implications for management. The importance of detailed and updated planning has been emphasized; however, if prior planning work is not completed properly, the benefits will be limited. Overall, the present results were preliminary, and more empirical research is needed.

Data Availability Statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (e.g., the video recordings). Information about the *Journal's* data-sharing policy can be found here: [http://ascelibrary.org/doi/10.1061/\(ASCE\)CO.1943-7862.0001263](http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263).

Acknowledgments

This research was partially funded by Business Finland project Digibuild (Grant No. 2758/31/2015).

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