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Construction Logistics Centres Proposing Kitting Service: Organization Analysis and Cost Mapping

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Abstract: The construction industry represents an important part of the global economy but is known for many issues such as harmful emissions, low productivity, waste generation, poor ergonomics, and construction incidents and accidents. A logistical view has proved to be a solid basis for improving construction performance while construction logistics centres (CLC) are gaining interest and proposing more services such as Kitting. Since the CLC-kitting-based approach is a new phenomenon, it is still a relatively unexplored topic. Hence, this paper addresses how this configuration could be applied to construction projects and what are its related costs information. The research design is based on a single case study showing the CLC-kitting use by a French general contractor in a student housing project. Data has been collected through site visits, observations, project documents, and discussions conducted with construction managers and logistics planners. Data analysis identified realized effects from deploying CLC-kitting in construction projects. Therefore, recommendations are provided, at both strategic and operational levels, which can be leveraged in similar projects. Finally, an identification of constructions logistics costs shows their distribution along the supply chain and was evaluated at 14.7% over material purchasing price.

Keywords: construction logistics; supply chain management; construction logistics centre (CLC); just-in-time (JIT); kitting; logistics costs

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1. Introduction

The construction sector has continuously faced challenges with regard to productivity, safety, quality, and environmental impact [1,2]. This has led the construction industry to innovate and rethink their project conceptualization and execution, via the exploration of continuous improvement techniques aimed at creating value for the client by eliminating waste. For example, industrialization [3], prefabrication [4], computer-integrated design, robotics, and automated construction techniques [5]. On the other hand, research has been conducted to find effective management strategies for construction projects.

A recent report by McKinsey [6], which highlights the issue of performance in construction, proposes seven levers to be activated. Construction site logistics and supply chain management (SCM) are among those since they are good vectors for improving the performance of construction sites [7,8].

Construction logistics deals with many technical, organizational, and environmental issues affecting the cost of a project, time, and quality of execution. Recently, construction logistics centres (CLC) are gaining more interest among general contractors who are trying to restructure their materials management methods along with their subcontractors and suppliers, especially in complex construction projects with sensitive urban contexts or confined sites. A CLC may provide more added-value services such as Kitting and just-in-time (JIT) delivery. Kitting consists of packing different materials and delivering them as one package while JIT delivery consists of delivering materials to construction sites, to be installed immediately without being stored [9]. Combining those two services will therefore allow to deliver the right quantity, at the right time, and in the right condition.

Construction logistics centre-kitting (CLC-kitting)-based approach is an emerging subject in the literature and still a relatively unexplored topic. A. Fredriksson et al. highlighted that there is limited information and knowledge regarding the initiation and organization of CLCs [10]. There is also a lack of experiences with CLCs solutions and services. Accordingly, empirical research should be conducted by focusing more on design and implementation [11].

Construction is a very cost-oriented industry, where stakeholders seek to be competitive by controlling and reducing their costs operations. Logistics activities are costly, especially in complex projects. Over the past decades, many practitioners have focused their efforts on reducing construction logistics costs [12]. Therefore, construction managers and planners need to better understand logistics activities and their related costs in order to have relevant information and take decisions that are more accurate [13].

Hence, this paper addresses how CLC-kitting configuration could be applied to a construction project and what are its related costs information.

2. Research Background

This section provides a comprehensive overview of construction logistics. Construction challenges involving logistics and construction logistics concepts are presented first. Then, this section explains why general contractors, subcontractors, and construction clients are approaching CLCs to manage their flow by listing construction peculiarities and traditional logistics limitations. This overview culminates in the introduction of CLCs (going through proposed services and kitting, operating model and different supply configurations) and by discussing the relevance of construction logistics costs and their attributes.

2.1. Construction Challenges Involving Logistics

On construction sites, 49.6% of work is non-value adding activities [14]. There are many underlying causes: human errors, waste during construction, delays in decision-making and instructions, lack of communication and planning, bad weather, lack of skilled manpower, and misuse of equipment or material [15].

Additional studies show that at least 6% of the total construction budget is dedicated only for handling during the final (architectural and technical) trades, 30–40% is allocated to materials [16], 1% is lost because of theft on-site [17], and 2–4% is dedicated to waste elimination [18]. Social issues are also involved: handling is at the origin of half of construction sector accidents [19]. That is why health insurance organizations are becoming increasingly strict and are asking general contractors to better organize the logistics of construction sites and provide appropriate handling tools for better ergonomics.

The environment is also affected: Estimations reveal that 15–20% of heavy goods vehicles in cities are related to construction. In the urban contexts, heavy vehicles are subject to strict traffic regulations and those constraints are also likely to become more restrictive in the coming years with new ecological measures imposed on urban freight transport [20].

2.2. Construction Logistics

Logistics is defined as the process of planning, implementing, and controlling the flow and storage of materials and related information from point of origin to point of final consumption. The purpose of logistics is to meet customer requirements in an efficient and cost-effective manner [21]. Based on this definition, logistics is a part of SCM, which also includes procurement, processing operations, and customer relations management. Transport, storage, handling, and waste evacuation are the most obvious activities of construction logistics. There are also financial and information flows that are more difficult to assess and to track accurately in a construction project. A systematic literature review to study the development of the SCM concept (including logistics) within the construction industry literature showed a recent and growing interest in the topic [22].

Construction logistics is plagued with several problems [23]. For example, companies are not able to inform of the availability of the goods they are supplying, to identify which materials had already arrived at the project site, and to locate them and which materials are already installed [24]. There are also many groups of materials, subcontractors and suppliers, which require a great effort of communication and coordination to ensure real-time information shared between stakeholders [25]. Construction industry logistics remains immature and the stakeholders do not understand how logistics can add value to projects [26]. Indeed, well-planned logistics require design effort and generate additional costs, but qare uickly compensated by the earnings since traditional material handling and material control logistics hide significant losses [27].

In fact, a materials management-related decision requires top management support. On the other hand, peculiarities of the construction industry make improvement strategies difficult to implement. The following have been identified as the main peculiarities:

- The production strategy is oriented towards subcontracting [28]: This strategy is based on the contractual transmission of responsibility and risks, including logistics. Subcontractors always have their own supply configurations, which can be more or less organized according to the size, deployed resources, and knowledge of the company.
- The multiplicity of stakeholders: Since there is an economic necessity to use local labor and materials, organization and stakeholders (subcontractors and suppliers) are temporary, even for the same kind of projects and the same general contractor. A national French study realized in 2016 shows the existence of about 560,000 construction companies with 96% of them having less than nine employees [29]. Recently, general contractors have made efforts to build sustainable partnerships with subcontractors and suppliers by shifting their attitudes to more strategic and long-term partnering philosophies [30].
- Each site is unique from a logistical point of view [31]: localization, internal and external access conditions, logistical means, and regulation constraints.

The actual practices show that each subcontractor/supplier delivers materials separately and directly to the construction site, which usually leads to the following consequences:

- Neighborhood disturbance, congestion in the delivery area, and consequently in the surrounding environment: 15% to 20% of heavy goods vehicles in cities are related to construction [20].
- Huge production of waste due to multiple material movements and disorganized storage: an investigation was carried out in Sweden on 14 construction sites and revealed that the waste varied from 4–27% of the delivered volume [32].
- Poor use of skilled labor and valuable time wasted in handling: H.R. Thomas et al. conducted a productivity study on a commercial construction project and estimated that ineffective materials management resulted in 19% as work time overrun [33]. A second study was carried out on housing projects in Sweden and showed that materials handling, which mainly includes transporting materials to the work place, took 14% of the work time [32].
- Project delays: construction logistics are exposed to variability, including incomplete or incorrect orders, and late deliveries. P. Josephson et al. conducted several studies investigating the causes of construction rework. Findings revealed that 17% of rework was mainly related to materials, of which late deliveries were responsible for 37% and wrong orders for 10% [34].
- Saturation of the logistic means of the construction site: handling tools and storage space [35].
- Client dissatisfaction, work team stress, and risk of accidents [36].

In order to manage logistics flows and address the aforementioned issues, some construction actors make use of a construction logistics centre (CLC) [11]. A previous study on London Construction Consolidation Centre (LCCC) revealed that using CLC increased productivity of the labour force by up to 30 min per day, and decreased freight journeys and delivery costs. The materials not being available reduced from 6% to 0.4%, and materials waste was 10% lower while delivery reliability achieved 97% [37].

2.3. Construction Logistics Centre

2.3.1. Overview

A CLC is a facility that is usually used for receipt, temporary storage, and redistribution of materials according to the construction site orders that are received. There is no common used term in the literature for this facility; some other designations are construction distribution centre or construction consolidation centre. CLCs are strategically located close to major traffic lines, usually equipped with transport management system TMS, and rarely equipped with warehouse management system WMS due to the multitude and complexity of construction materials references and suppliers. The introduction of CLC in a construction project aims at better match of supply and demand and proposes deliveries on just-in-time basis.

JIT: Just-in-time logistics has been introduced as part of the concept of lean construction and consists on delivering materials to construction sites, to be installed immediately without being stored [9]. The application of JIT principles has had a great influence by reducing delivery times and lowering inventories on site [38]. JIT requires more involvement of suppliers, carriers, and construction managers, since it is based on delivering smaller batches more often to site and lowering the inventory, which can be achieved thanks to CLC implementation. However, JIT deliveries do not necessarily include centralized logistics control in the supply chain.

The earliest example of a CLC being used to support construction projects was the one established by British Airports Authority (BAA) at London's Heathrow Airport in 2001. Coincidentally and independently, an almost identical facility—the Logistik Center—was being developed at the same time in Stockholm, Sweden to serve a large residential project [39].

There are several core operational functions in a CLC:

- Receive and put-away: scheduling arrivals, receipt of materials, unloading, verifying (inspection for damage, short, incomplete), materials handling, and moving to the storage location.
- Store: physically hold the material and consume space for a limited time.
- Pick, pack, and ship: moving items from storage based on orders, check order for completeness, and then load vehicle.

A CLC facility may propose additional value-added services such as kitting, prefabrication [40], handling onsite [41], and waste evacuation.

Kitting: The kitting is a process that consists of packing-related (e.g., same planning sequence/workplace) but separate materials (e.g., different suppliers/trades), and delivering them as one package or unit. Therefore, different parts are consolidated and delivered together since they are on the same planning sequence and installed in the same workplace [42]. From a logistical perspective, the kitting alternative is expected to make the organization within the site easier and provide the basis for the smooth implementation of JIT while delivering the right quantity to the right place [43,44].

2.3.2. Operating Model

A CLC-based approach involves many actors. That means it is necessary to have a clear and common understanding of the operating model for different actors that will serve on all stages. The clear definition of role and responsibility of each actor simplify the flow of information. In practice (Figure 1), each trade supplier delivers products directly to the CLC. The products are received and stored there (for an average of two weeks) before being delivered to the construction site at the point of use and on a just-in-time and right quantity basis, on-demand, and according to a common supply schedule between the different trades. Some heavy and bulky products (prefabricated concrete elements, steel reinforcements, wall panels) are delivered directly on site. The approach may also include the return of unused goods, mis-ordered products, and packaging waste evacuation.

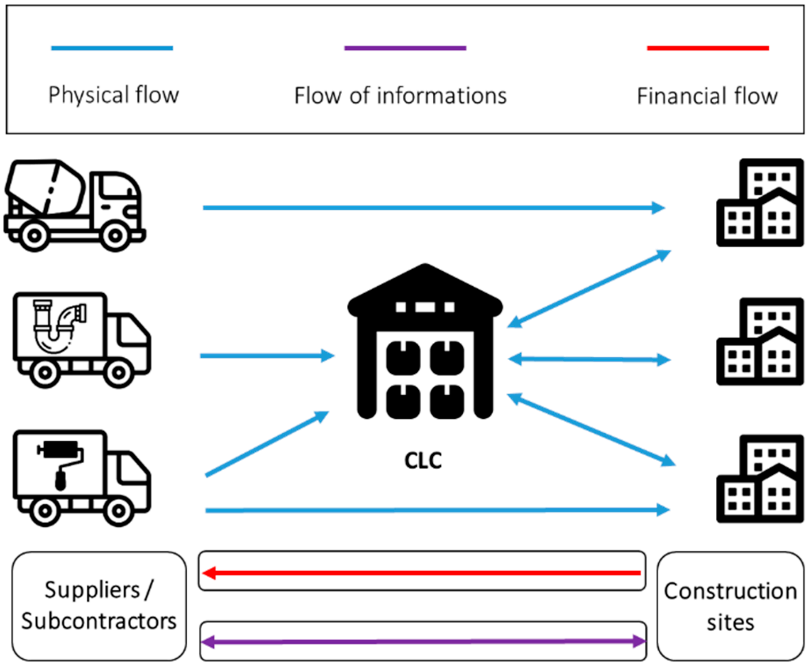

Figure 1. Construction logistics centre operating model.

2.3.3. Different Configurations

In most cases, a non-local CLC is used, which means an external space capable of serving several construction sites. It is also possible to imagine a local CLC that would be located on the construction site itself. This implies that there is sufficient space on site and requires a temporary warehouse installation to protect materials from bad weather and theft.

There is another factor to consider: The CLC either can be subcontracted (external) or managed internally by the general contractor. A middle configuration also exists, called semi-external: the general contractor does administrative and economic management, and an external logistics operator carries out logistics operations (especially transport). The distribution of responsibilities and risks differs for each configuration.

Sites observations and discussions with construction managers and logistics planners have shown the existence of six different supply configurations following the use or not of a CLC and kitting (Table 1):

Table 1. Different supply configurations according to the use or not of CLC and kitting.

	Without CLC	With CLC
Without kitting	Direct deliveries on site.	Transit through the CLC and JIT delivery.
With kitting	Delivery of materials separately and kitting on site.	Delivery of materials separately and kitting on CLC.
	Supplier proposes kitting and delivers on site.	Supplier proposes kitting and delivers on CLC.

Therefore, well-designed logistics is a combination of the aforementioned configurations, with relevant choices according to the different constraints of materials, construction site, and project.

2.4. Construction Logistics Costs

Construction is a very cost-oriented industry, where stakeholders seek to be competitive by reducing their costs operations and increasing their profits [39]. The cost aspect has been promoted in the selection of sub-contractors, which is mainly based on the financial criteria instead of performance and management skills. Reducing the cost of materials through selecting a cheaper supplier is also a widely known practice since material costs amount to 30–40% of total construction costs [16,45].

Over the past decades, many practitioners have focused their efforts on reducing construction logistics costs. They are considering efficiency as a necessity and cost control as their main priority [46].

Logistics activities are costly, especially in complex construction projects with sensitive urban context or confined sites. Therefore, the associated costs should be identified, well-understood, and controlled. For example, targeting low prices by ordering larger quantities will lead to increased storage and damage costs [12].

L. C. Bell et al. conducted two research projects to determine the attributes, costs, and benefits of well-planned and executed materials management systems. The most significant benefit that can be derived is the savings associated with improved labor productivity, which is estimated at 6% [27]. The importance of logistics cost has also been highlighted in an empirical study in Finland, which estimated that the total logistics costs for the supply of plasterboard could account for 27% of its purchase price [47]. S. Amornsawadwatana et al. proposed a logistics cost structure in a construction project as follows: ordering, transport, inventory, and damage [48]. The proposed methodology was then applied to an actual building construction case study and calculated logistics costs, as percentages of material purchasing costs (65% for bricks and 13% for cement).

Y. Fang et al. proposed an activity-based costing approach for construction logistics cost analysis and applied it to precast concrete. The purpose was to increase the understanding of managers and planners on construction logistics activities and their related costs. Four types of construction logistics costs were considered, including: inventory, transportation, site storage, and procurement costs [13]. H. Said et al. developed a new optimization model that is capable of generating optimal material procurement and layout decisions in order to minimize construction logistics costs [49]. The costs components covered material ordering, financing, stock-out, and layout. Another optimization model was developed later and a case study illustrated that total construction logistics costs were reduced by 8.4% for the whole project [50].

The logistics cost structure is different for each supply configuration. Therefore, the identification of the costs components must be adjusted according to the related context and the project being studied. While several studies on CLC and kitting have been conducted by researchers, the investigation of its costs is still a relatively unexplored topic. In the following case study, a CLC-kitting-based approach is investigated and the related costs information are presented.

3. Methodology

This paper addresses how CLC-kitting configuration could be applied to a construction project and what the related costs information are. To achieve the purpose of this study, a single case study research design was used. CLC-kitting is an emerging topic in the literature and according to R. Yin, a case study is an in-depth investigation of a contemporary phenomenon [51]. Moreover, a case research design is the best suited to address the how, why, and what kinds of research questions aimed at exploring and understanding some phenomenon in depth [51]. The case was prepared through a comprehensive overview of construction logistics, CLCs organization, and construction logistics costs.

The studied case is a real implementation of CLC-kitting configuration in a student housing project, done by a French general contractor in the greater Paris region. The general contractor is responsible for a large part of construction activity in France and housing projects are recurrent and represent the leading activity at the European level. Multiple cases studies could provide a more in-depth understanding of the phenomena than a single case. However, CLC-kitting is still in its infancy and the studied project is one of the first experimentations of the general contractor. Therefore, it is not yet possible to have more feedback from additional projects.

Data were collected from January 2019 until August 2019 when the project was finally delivered to the client. Technical and architectural trades were carried out during this timeframe and this study focuses only on materials subject to CLC-kitting-based approach. Multiple data sources and collection methods were used to enhance the validity and reliability of the paper. For each part of the case study, data collection and analysis were conducted as follows:

Starting with CLC-kitting organization, the main sources were the following: review of site access plans, on-site visits, participatory observations, and semi-structured interviews with construction managers and logistics planners. CLC was visited three times while a weekly point was made with a referent on the site to discuss the CLC-kitting progress. Semi-structured interviews were conducted with four construction managers on-site and two logistics planners on CLC. Interviews focused on identifying both the benefits and disadvantages of CLC-kitting supply system.

Data analysis, therefore, allowed recommendations to be provided, at both strategic and operational levels, which can be leveraged in similar projects for better implementation. In fact, a case study allows readers to test learned lessons in other cases or situations, leading to transferability, which is different from the generalization that occurs in quantitative studies [52].

For CLC-kitting costs, data were collected through review of project documents, including CLC and suppliers invoices, prices lists, and project financial balance. An identification of constructions logistics costs shows their distribution and evolution along the supply chain from ordering to packaging waste evacuation.

Finally, the findings of this paper are discussed within similar literature while identifying the next perspectives of this research project.

4. Case Study: Construction Logistics Centre Application

4.1. Project Overview

The case study is the construction of a student housing project in the greater Paris region (Figure 2). The project duration was 19 months, starting from structural work performed by the general contractor and ending with the final trades performed by subcontractors, although material purchasing was still under the general contractor's responsibility. The final trades, which include all the technical and architectural trades, are as follows: electricity, HVAC, plumbing, locksmithing, painting, insulation, flooring, and carpentry.

The construction site is characterized by a lack of storage space and the Paris region is known for complicated traffic conditions. Those constraints led the construction team to use a semi external CLC, located 35–60 min away from the construction site. The materials that pass through the centre represented 48% of final trades products in terms of purchasing cost, and are packed into three kits:

- Kit 1: Tilling, plumbing, and HVAC.
- Kit 2: Doors and related equipment, baseboards, closet, and flexible floor.
- Kit 3: Sink and bathroom furniture, electrical apparatus, and kitchenette (including connections).

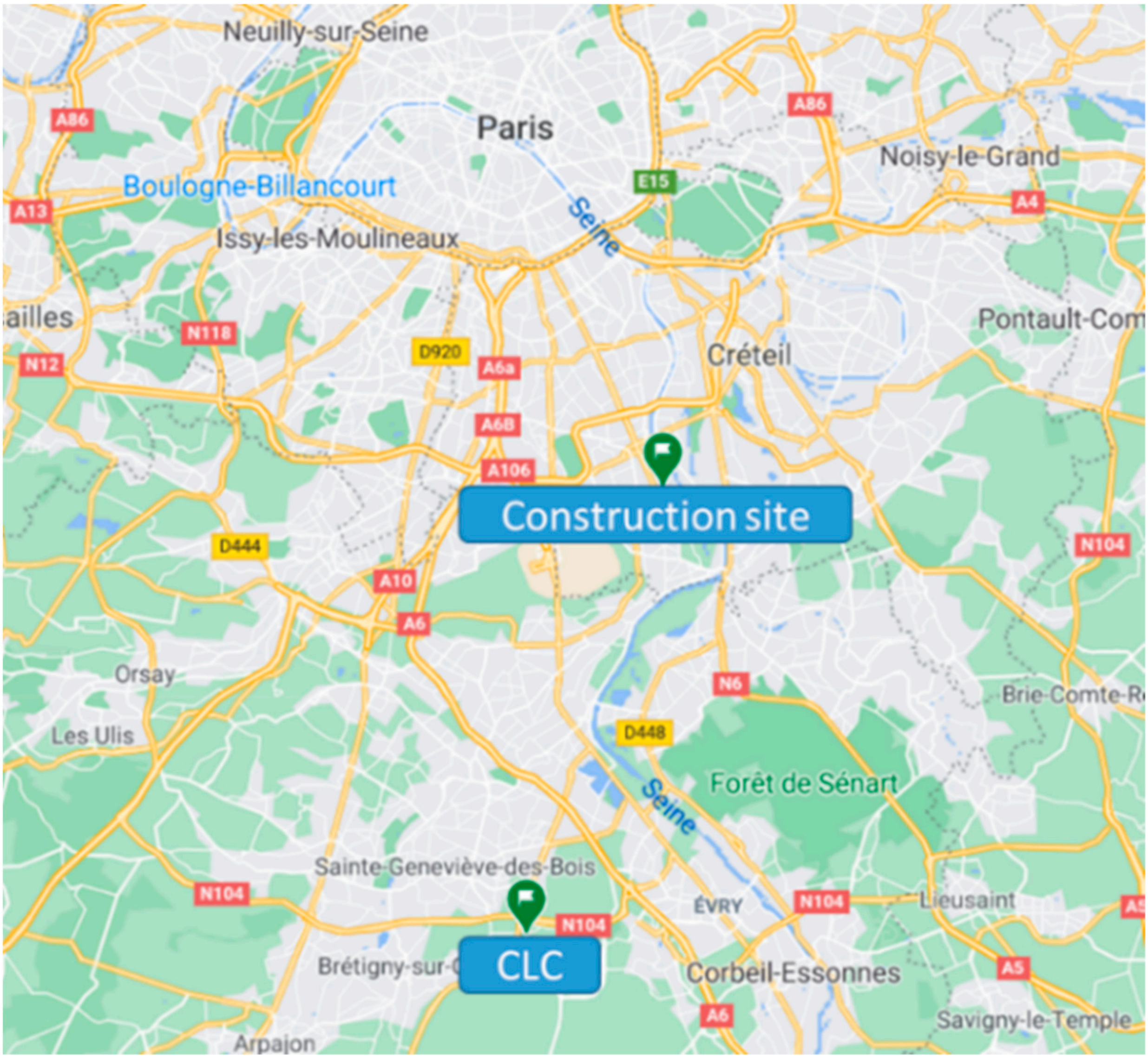

Figure 2. Construction site and CLC locations (Adapted from: Google Maps).

The project logistics workflow is illustrated in Figure 3:

In an early phase of the project, the general contractor sales department order the total required quantities. As the work progresses, the construction management team releases partial deliveries by indicating to suppliers, the CLC as delivery address. For consumable materials or materials not anticipated during the design phase, construction managers can directly place orders on an online platform, which is connected to the general contractor suppliers' database. CLC then receives different suppliers' deliveries and a team is responsible for the preparation of the kits before being stored.

Two days before being used on site, the construction team requests kits delivery. CLC prepares the truck delivery, as shown in Figure 4. Once arrived at the site, a team is responsible for materials handling inside the building and dispatching the kits items in students rooms. During the dispatching, the team checks the delivered materials based on a sheet prepared in advance for each room.

Handling and dispatching has been made easier thanks to the early commissioning of the building elevator. At the end of the team intervention, waste related to kits packaging is sent back to the platform, allowing the truck to be used on their way back.

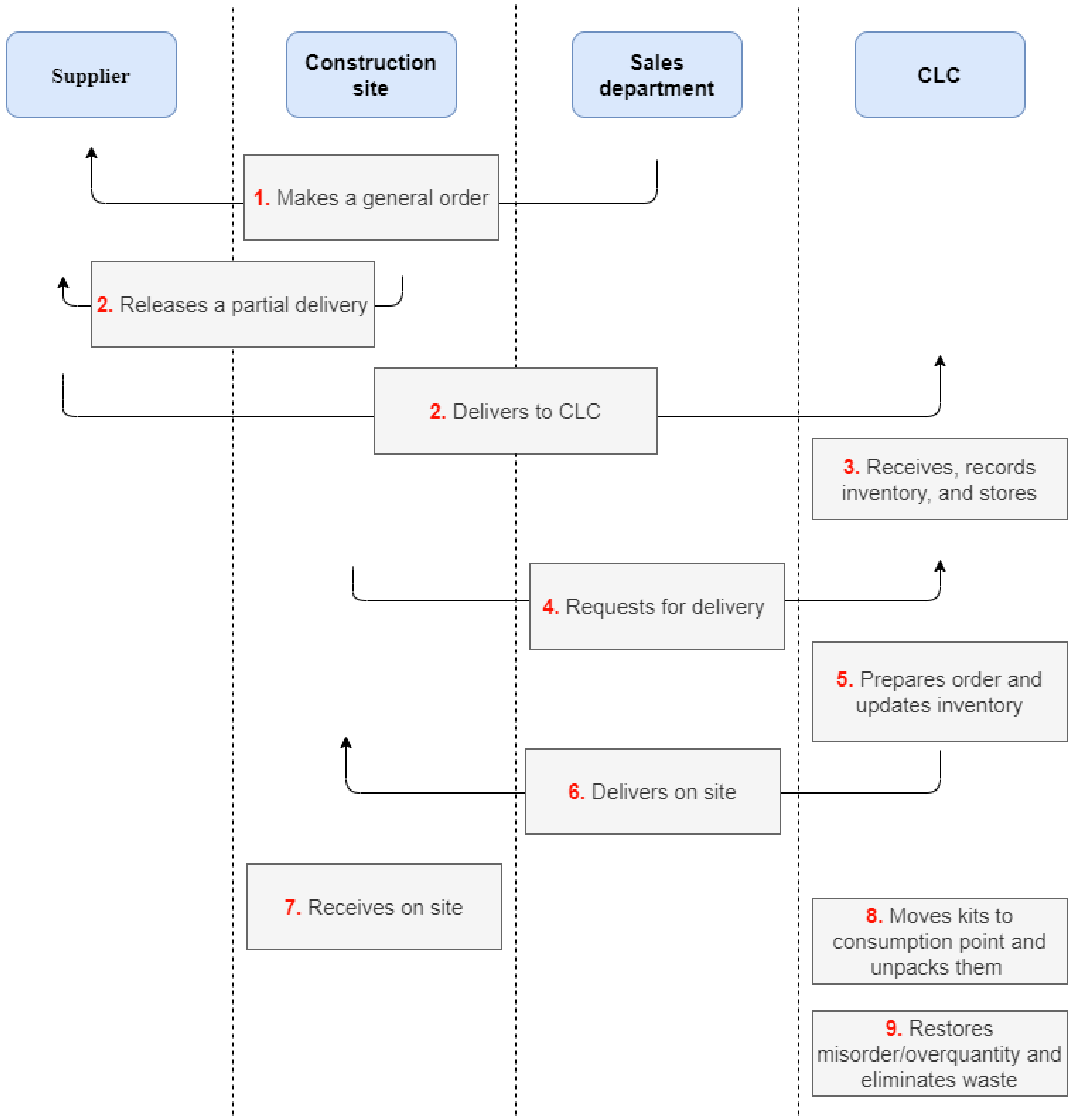

Figure 3. Workflow of the construction project logistics.

4.2. General Analysis

Table 2 summarizes the main reported benefits and disadvantages, according to the case study and along references to previous research studies on CLCs. Six benefits and five disadvantages were identified and all are recognized in the literature.

Table 2. Pros and cons of the CLC-kitting-based approach.

Pros	Cons
Save workers time with better advancement [10,37,41,53]	Need management in advance by construction managers [11]
Less handling and improved ergonomics [11,37,41,53]	The construction team must anticipate both CLC and suppliers delays [10,11]
Fewer deliveries and more space on site [11,37,43,53]	More intermediaries in the supply chain [10,11]
Exact quantity arriving just-in-time and in the exact place (better match of supply and demand) [37,53]	Handlers are not necessarily familiar with the construction process [11]
Product accessible within 48 h [53]	More difficulties to control inventory [10]
Facilitates packaging waste disposal [37,53]	

Figure 4. Truck delivery preparation at the CLC.

Starting with the reported benefits, construction managers found that the platform had helped them save over the entire duration of the work and have more flexibility in planning. In particular, on the supplies to the building, which required less labor: handling is no longer the ancillary task of the skilled labor but the main mission of the handlers who supply the site. This approach, therefore, allowed better control of handling practices on the site and brought them into line with regulations.

Besides, this solution has reduced the number of deliveries on-site, by grouping several suppliers materials on packed kits and consolidated deliveries. This service has also influenced the trades to work positively: starting work with the material already in place to install facilitates their advancement, and they have not systematically claimed missing or wrong material. Products were also accessible with an improved lead-time, and the CLC showed reliable deliveries for requests of less than 48 h. Construction managers also appreciated the packaging waste disposal, performed by CLC teams at the end of each intervention, which resulted in better-organized workspace.

Turning to the disadvantages that have been identified in this study. The CLC-kitting-based approach needed an early planning, thus construction managers had to manage more in advance and anticipate both CLC and suppliers delays. In addition, handlers being part of CLC teams were not familiar with all construction materials references, which limited their autonomy and requested the intervention of the on-site team to guide them in some occasions. The most important area that needed improvement is inventory control. The inventory checking in CLC was done for the largest items, but some deliveries contained many different small parts, which made the inventories harder and lead sometimes to several unpleasant surprises on the remaining quantities and have requested material re-order.

This case study being among the first utilizations of CLC and kitting in general contractor projects, a feedback for continuous improvement is necessary. Therefore, a general analysis reveals that more attention should be paid to the following elements for the next experimentations:

At the strategic level:

- Subcontractors must reorganize for the next implementations: the assignment of personnel must take into account the CLC-kitting approach, which allows for faster progress. Otherwise, no gain will be recovered, neither for general contractor nor for subcontractors.
- The general contractor must renegotiate with subcontractors: contracts and prices must take into account the costs of the new logistics configuration as well as the potential gains. That is why partnerships have become a priority for general contractors.
- Furniture supply and installation subcontracting: This production strategy is an advantage for the general contractor since it gives transparency on prices and allows potential gains on materials cost. On the other hand, it is necessary to ensure good communication with the subcontractors and assume responsibilities and risks related to the supply of materials.
- A clear contract between CLC and general contractor: explanation of operating mode, clear definition of responsibilities and risks during reception and storage, and clarification of exact quantities on delivery invoices.
- The CLC is able to negotiate better discounts and offer lower buying costs: In the case of an internally managed CLC, the general contractor will have the advantage of negotiating prices.

At the operational level:

- Elevator anticipatory commissioning is very useful, however, it is necessary to make sure of the manufacturing lead times and of the availability of the installation team. Otherwise, a construction site should improvise and call for additional handling services, which leads to unanticipated over costs. It is also necessary to ensure the good protection of the elevator so that it can be delivered to the client in good condition and without damage.
- A follow-up sheet for each kit is confirmed as a good practice: while dispatching at the workplace, the team double checks the delivered elements based on a sheet prepared in advance for every unit (room, apartment . . .).
- Process anticipation and control: In the early project phase, the construction management team coordinates with the CLC to implement initial tests (e.g., one room/apartment) in order to document suppliers delays, operating model, and verify prepared kits compliance at CLC. Kit notion should be clearly understood: Sometimes a kit may contain more than one pallet, depending on products consolidated and the unit size (e.g., apartment/room).
- Construction logistics planning document: a logistics document should be established as a common understanding between general contractor, suppliers, subcontractors, and CLC. The main noted information are: materials, quantities, supply configurations, and construction site access plans. Tools to use for horizontal and vertical supply should be prescribed and studied in advance to avoid saturation issues.

4.3. Costs Structure and Evaluation

According to logistics activities presented in Figure 3, the considered cost attributes are the following: supply organization (including ordering), reception, storage, kitting, handling and dispatching, and packaging waste evacuation.

Many factors can drive up the logistics cost, and it is necessary to identify which are the most cost-sensitive elements within a logistics system such that appropriate actions can be taken to control and reduce the cost. The identification and evaluation of the logistics costs related to the case study, showed the following shares within the supply chain, starting from ordering and ending with waste evacuation (Figure 5):

- Supply organization (17%): a member of the construction management team was responsible for ordering, coordination with CLC, checking, receiving, and dispatching.
- Reception (1%): cost of deliveries reception at CLC.

- Storage (16%): cost of the space allocated (300 m^2) at CLC for the duration of trades work.
- Transport (24%): cost of transport from CLC to the construction site.
- Kitting, handling and dispatching on-site (41%): A team was responsible for the preparation of three kits inside the CLC. Once kits are delivered to the construction site, the same team is also responsible for handling and moving them to the final use point inside the building. It is a high value- added service since dispatching operation also allows to double check delivered materials.
- Packaging waste elimination (1%): disposal of the waste that came from kits packaging and cardboard boxes.

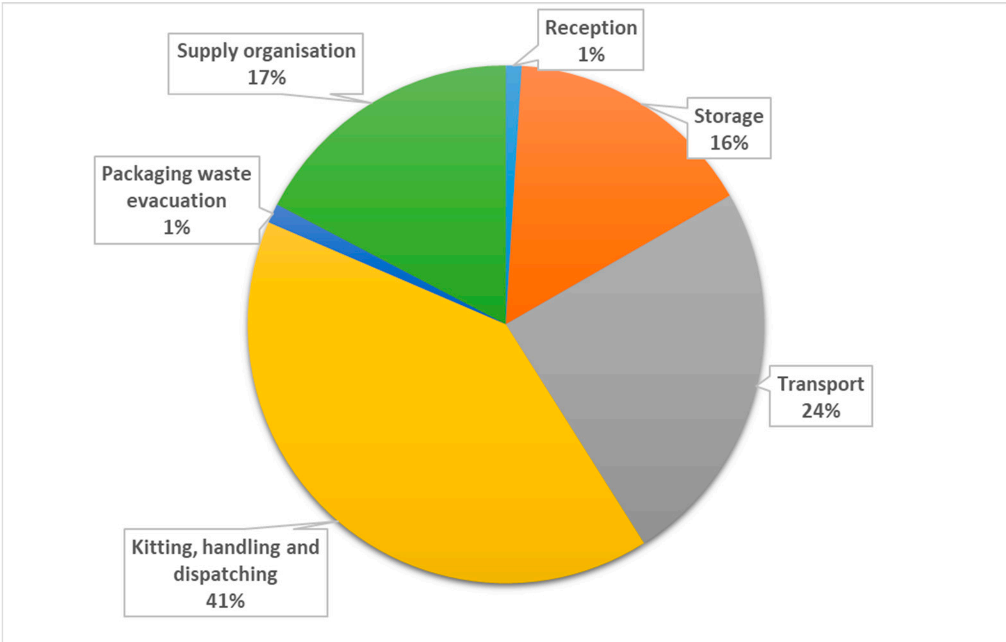

Figure 5. Logistics costs repartition of kits.

Figure 6 summarizes the evolution of logistics costs within the supply chain of the CLC-based approach combined with kitting. Results show that compared to the purchasing price of kits material, 14.68% were associate with logistics cost overruns. That means that for each material purchased at 100 €, it took on average an extra of 14.68 € to get the material to the point of use and dispose its packaging waste.

Research studies on CLC-kitting-based approaches and their costs are very limited. On the other hand, some previous research work has focused on the costs of traditional supply chains. A conducted study on four construction sites in Finland has shown that the costs of traditional logistics varied from 17% to 27% over materials purchasing costs [54], including transport costs, which varied from 4% to 8%. Transport costs were also highlighted in a study in the United States and showed that their values varied between 4% and 10% [12]. Transport costs evaluation in this study (3.54%) is still slightly beneath the aforementioned values. In fact, during our observations, the trucks coming from CLC allowed for maximal efficiency and optimal loading factor (around 90%), while the trucks coming directly from suppliers to the construction site had partial loading. A recent study on four European construction projects with traditional supply chains has shown that the average loading factor is around 75% [55]. The CLC-Kitting consolidates deliveries, reduces the number of trips, and therefore results in improved transport costs.

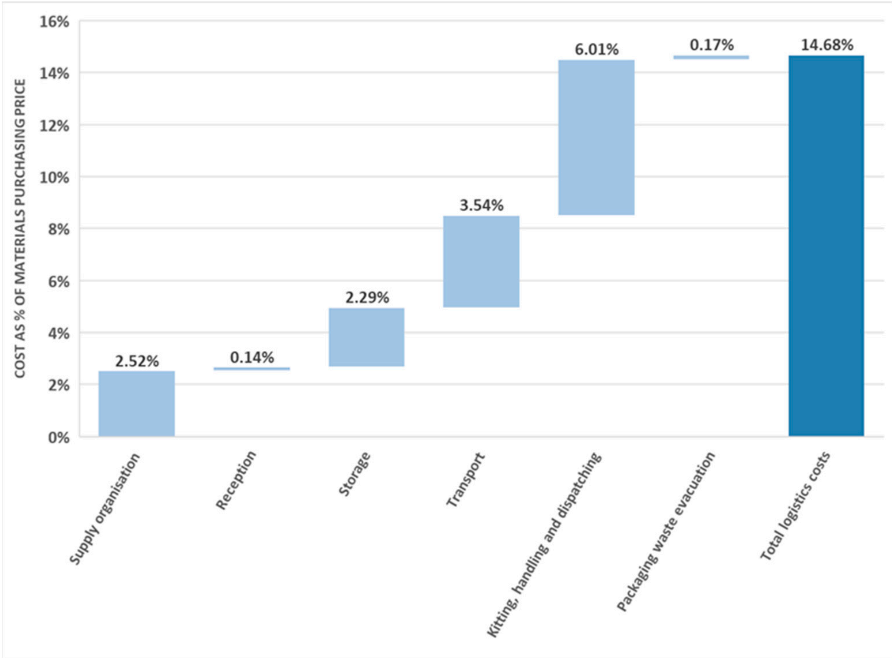

Figure 6. Logistics cost staircase of kits as percentage of purchasing price.

An additional study was carried out in Sweden on housing projects and revealed that materials handling costs accounted for 11% of materials purchasing costs. Those costs were reduced by 20% when the operation was out-sourced to an external logistician [41]. Handling efficiency is indeed a crucial factor in construction performance, since craftsmen spent around 14% of their working time moving materials to the assembly area [32]. However, out-sourcing materials handling generates savings only on vertical supply. Construction workers still have to dispatch pallets, check right references, assume horizontal handling, and transport the right quantities to the right place. Therefore, using kitting service and out-sourcing materials handling reduces the aforementioned operations. A. Sobotka et al. conducted cost simulations in Poland and indicated that out-sourcing the supply logistics process reduces production costs [56].

Studies from construction logistics literature were conducted on different projects, materials, using different assumptions, and cost structures. However, those results could be considered as guidelines to understand CLC-kitting-based approach costs and they can serve as a basis for gradually improving construction companies performance [47].

5. Discussion and Conclusions

Logistics represents a great part of construction costs and has been identified at the same time as a lever of the construction industry performance. One potential solution for improving construction logistics is a CLC combined with a kitting-based approach. This paper investigated this solution by setting up the basis for a common understanding and then showed a case study that used this approach. The purpose was to investigate the implementation of CLC-kitting supply system and to show its related costs information.

Effects from deploying CLC-kitting were reported. This supply system reduced deliveries, saved workers time, and improved ergonomics. On the hand, the case study showed the need of more planning and management in advance, as well as more difficulties to control inventory. Guidelines were provided, at both strategic and operational level, for better implementation. Strategic actions should focus mainly on subcontractors integration and CLC-kitting contract definition, while operational actions included process anticipation and a construction logistics planning document.

The case study also illustrated logistics activities and their costs evaluation within the supply chain, starting by ordering and ending with delivering to the final use point in the building and waste packaging evacuation. Total logistics costs were evaluated at 14.7% over material purchasing price, of which preparation of kits, transport, and materials handling have the largest shares. Those measures could be used as a basis for monitoring logistics performance, and as a result, progressive improvement of company productivity.

At the end of this study, a resulting question was naturally formulated on financial savings and their measurement is considered as a next step of this research. Based on CLC-kitting advantages reported in Table 2, the following elements were identified to be measured in the next experimentations:

- The rate of waste reduction: external and secure storage aims to reduce waste, losses, and thefts.
- Work time savings: Using kitting service and out-sourcing materials handling has allowed craftsmen to concentrate more on their installation tasks and less on horizontal and vertical supply. The project management team also spent significant time dealing with logistics issues and, therefore, assigning these tasks to a logistics operator reduces the workload.

Relying on a CLC aims to better plan supplies and reduce variability. In addition to the potentials benefits mentioned above, gains that are more general are captured thanks to meeting deadlines and are related to variable construction site costs (e.g., equipment rental) and management team costs. The entire project team agreed on the importance of conducting an integral financial study and identifying both costs and savings. This step is able to accelerate the implementation of CLCs and strategic recommendations mentioned in Section 4.2. Firstly, it is a strong argument to convince subcontractors to accept the use of a CLC and build a long-term partnership. Secondly, financial study is a solid basis for subcontractors to reorganize for future implementations and for all stakeholders to agree on the best formula of costs and benefits distribution.

This work is of course not free of limitations. Organizational analysis and costs evaluation were global, since the case study is one of the first implementations of CLC-kitting-based approach by the general contractor and the model still in its early stage of application and investigation. However, the findings from this paper established a valuable starting point for further studies. Other projects running under CLC-kitting supply system should be investigated to determine whether similar conclusions could be drawn.

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