Smart logistics for urban construction sites (CCC)

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Abstract. The traditional construction logistics is managed in silos, which leads to time losses on sites and increased project costs due to repeated handling/moving of materials. Moreover, these uncontrolled flows of deliveries also have a proved environmental impact. Alternative approaches intend to centralize these flows using a Construction Consolidation Centre (CCC), which allows to deliver material just-in-time as a kit, directly at the workplace. The purpose of this research is to evaluate if this supply chain management methods can drive the construction sectors towards more efficient and sustainable practices. Therefore, this paper describes, from the General Contractor’s perspective, the implementation of a CCC between 2019 and 2020 for a Residential Tower project, for the first time in Luxembourg. Increased productivity, reduced costs, and reduced carbon footprint of the transportation flows were observed based on measures throughout the entire project. Beyond these evidences that more sustainable practices are achievable in construction, the paper discusses adherence of workers and subcontractors as well as organisational and technological prerequisites and perspectives. Accordingly, this collaborative model appears as a relevant way to build and strengthen partnerships between the construction stakeholders by improving day-to-day work. Therefore, CCC and kitting appear as a practical solution for the current economic and environmental challenges and more awareness should be put on this topic to allow its diffusion to the whole sector.

Keywords: Construction logistics, case study, CCC, kitting, sustainability

1. Context

1.1. Introduction

Construction, and more specifically construction logistics, is widely considered as one of the main contributors to the climate change. For example in the Netherlands, 27% of all greenhouse gas emissions in 2015 are attributable to construction logistics [1] and, with 30% of transported tonnage in a city, construction logistics is one of the main sources of disturbances in urban areas [1]. To reduce these impacts in a highly competitive context, the economic and social impacts must be considered at a sector’s scale [2]. The uncontrolled management of materials on construction sites causes material damages and losses, thefts and repetitive handling/moving of materials on site, with a direct impact on productivity and costs emphasized by many authors [3],[4],[5]. This article investigates the applicability of a new Supply Chain management paradigm in construction in order to tackle both environmental and economic challenges of the sector based on a real case. The contribution of this model to project
management in construction, the opportunity to trigger change at a sector’s scale and the impact of digitalisation will be discussed accordingly from a General Contractor’s perspective.

1.2. Research background

1.2.1. Concept. A construction consolidation centre (CCC) is a logistics platform located near an urban centre that provides suppliers with easy access for the delivery of their goods and a space suitable for manoeuvring and unloading trucks [6]. Figure 1 below shows the configuration when there is no CCC and Figure 2 when there is one. Suppliers deliver to the CCC instead of directly to the construction site. The material is unloaded in a dry and secure location with appropriate equipment. When needed on site, the logistician consolidates the requested materials and delivers them on time.

![Figure 1. Situation without CCC.](image1)

![Figure 2. Situation with CCC.](image2)

1.2.2. Expected benefits. This model was studied through simulations in different cities and demonstrated a strong potential for environmental impacts reduction as well as under 1 year payback (figure 3).

![Figure 3. Expected impacts of CCC in various simulated contexts [6].](image3)

1.2.3. Previous case studies. The CCC’s model can support several services. Amongst them, kitting consists in delivering the material at the workspace where it will be installed (e.g. directly in an apartment) based on just-in-time principles [7]. Recent studies demonstrated cost savings of 19.6% of labour costs in Finland [5], while advocating for a more comprehensive model of costs integrating reduced wastes on construction site [2]. When managed by an external company, the CCC can be linked
to the practice referred as TPL, Third-Party Logistics [8] where a specialized actor takes over part of the logistics management. Despite reported benefits, further studies of the cost structure are needed. This is especially relevant from a General Contractor’s perspective who might consider setting up and operating its own warehouse.

Despite theoretical and empirical evidence, there is a need to for more awareness on construction logistics in the construction sector based on empirical feedbacks [8], especially regarding the repartition of logistics costs [8]. Moreover, a new logistics paradigm also raises new challenges on construction sites [2] that should be tackled in order to foster transition at a sector’s scale. Accordingly, this paper provides in-depth analysis of economic and environmental impacts from a real case study where CCC, kitting and TPL were implemented jointly. A previous article was published on this case study, focusing on the demonstration of the economic and environmental relevance of this concept and on its contribution to the Lean Construction body of knowledge [10]. This article complements the previous publication by emphasizing operational feedbacks from a General Contractor in order to 1° demonstrate how consolidated construction logistics can be successfully applied with economic and environmental benefits, 2° how this model can be scaled up and further improve its efficiency.

2. Case Study: AUREA Tower

2.1. Research Methodology
To establish operational feedback from a construction site, an empirical approach is necessary. Hence, this research was conducted by the General Contractor during the first implementation of a CCC using TPL and kitting in Luxembourg with the support of a research centre. Due to the uniqueness of each construction project, no other construction site available at that time presented enough similarities to perform a comparative analysis. Therefore, the established methodology for evaluating impacts of the site consisted in:

1. Data collection of all the actual costs related to logistics, based on direct access to the site’s financial results.
2. Estimation of alternative delivery scenario with the subcontractor on a bi-weekly basis, based on actual needs and constraints (storage space available and delivery timeslots).
3. Identification on Non-Value-Adding (NVA) activities based on interviews and samples of measures.
4. Comparative time measurement on the same project for specific activities with or without kitting.
5. Survey of workers, subcontractors managers, General Contractor’s managers and logistics operator’s team.

2.2. Project Overview

2.2.1. Description. The AUREA tower project consists of the construction of a building of 138 apartments on 15 levels, with a total surface of 22,000 m². The Compagnie Luxembourgoise d’Entreprises (CLE), a subsidiary of the CFE group, is involved in this operation as a General Contractor for an amount of approximately 35M€. The project’s location, in a crowded urban area with very limited access, the low storage capacity on site and a tight schedule initially triggered the will to experiment just-in-time deliveries. The participation to the test had to be negotiated with every subcontractor and the following trades adhered to the initiative: ventilation and sanitation (baths, showers, radiators, toilets and equipment), tilling and parquet (includes adhesive and joints) and interior doors / main doors. The chosen logistics operator provided a warehouse 19 km away from the site and a storage area of 30,000 m². The experiment lasted 9 months (November 2019 to July 2020) for a total of 1,375 pallets delivered with support and monitoring of the Luxembourg Institute of Science and Technology.
2.2.2. Operational Workflow and digital tool. The shared objective of the General Contractor, the subcontractors and the logistician operator was to reduce NVA activities to its minimal extend. This implied to:
- Reduce time spent on handling operations for the subcontractors by delivering the exact material needed for each task of each apartments as a kit in the apartment.
- Reduce coactivity at the floors and the congestion of the unique lift of the site (fig 5-right) by performing the deliveries out of the working hours of the subcontractors.
- Reduce CO₂ emissions, time losses and costs for the logistics operator by maximizing load factors and performing deliveries out of the very dense traffic jam in Luxembourg. Therefore, the deliveries were performed after 4:00PM and planned collaboratively with both the subcontractor and the TPL operator. This was managed weekly during Last Planner System’s (LPS) meetings on site and using a dedicated digital platform as described in figure 4.

![Diagram of Kit definition and delivery workflow.](image)

Figure 4. Kit definition and delivery workflow.

Each of the apartments being finished according to customized buyer’s choices, a “kit” was not a standardized and predefined set of materials. All of kits for the 138 apartments had to be defined individually with exact contents (product references) and prepared accordingly (figure 5-left). Moreover, the material was owned by the subcontractors but managed by a third-party company in contractual relationship with the General Contractor. As a consequence, the need for traceability was very high and the status of the material had to be known at any time in the workflow. Arguably, this amount of data could not have been managed for the 1,105 kits of the project in real time with remote access for subcontractors and CCC operator without an adapted digital platform.
3. Results

3.1. Operational feedback

Beyond the figures, operational feedbacks were considered key by the General Contractor to capture the actual impact on daily practices on site, and therefore they assess the scalability of this new logistics model. Therefore, managers and workers involved in the experimentation had to answer a survey. This includes 6 managers (mostly project managers), and 9 subcontractors (foremen and workers).

3.1.1 Site staff (G.C.) and subcontractors. In the survey conducted within managers at the end of the experimentations, all of the 6 managers involved in the study stated an either light (for 33% of them) or significant (for 66% of them) improvement in productivity, planning reliability and transparency (fig. 5). Moreover, the implementation of the CCC had a low impact on their workload, as it represented less than 10% of their working time (and even less than 5% for most of them). All the managers declared themselves willing to use a CCC again for their next project and half of them considered that the model should be extended to further trades, such as electricity works, plaster works and waste management.

3.1.2 Subcontractors. Through their workers being directly involved in the field, subcontractors have highlighted a gain in comfort at work, clarity on the tasks to be accomplished and an improvement in productivity. 89% of them stated that the CCC model saves time and increases their productivity.

3.1.3 TPL operator’s. In the web platform, the logistics operator could declare any issue or non-compliance for materials delivered at the CCC. The overall rate of “fully satisfying deliveries” of 44% may indicate an inefficient integration of upstream suppliers. However, the evolution of these feedbacks through time shows that almost all of these issues occurred during the first 2 months (fig. 7).

Figure 5: Kit examples and unique lift of the site.
Figure 6. Evolution of comments over time.

On the other hand, the 98.5% of deliveries performed by the TPL operator were conform (the right material, at the right place and at the right moment). Considering that the TPL operator’s crew had never worked in the construction sector before, these results indicate that there was a learning period for all three suppliers, logistics operator and GC but that the model was efficient on the long run.

3.2. Impact on productivity

3.2.1 Reliability of schedule and increased productivity. The qualitative feedbacks of workers regarding productivity improvement were confirmed by the measure of actual cycle times. For the task using this kitting methods (and when removing cases impacted by a clearly identified external factor such as Covid, insufficient workforce or missing plans) a cumulated total of 74 days were gained compared to initially planned cycle time. This would represent a ~15% productivity increase.

3.2.2. Waste and NVA on site. This productivity gains on site are explained by the outsourcing of Non-Value Adding activities and their transfer to the TPL operator. These Non-Value Adding activities were identified with the subcontractors and comparative measures were performed on tasks without kitting in the same context (the same project and time period) to be used as a reference for calculation. Accordingly, following Non-Value Adding activities on site were reported (table 1):

Table 1. Non-value Adding activities measured in case study

| Non-Value Adding activity | Calculation method | Estimated Impacts for traditional logistics compared to kitting |
|--------------------------|--------------------|---------------------------------------------------------------|
| Unloading of the trucks and distribution to storage zone and to workspace (ST) | Calculated based on the estimated number of deliveries without CCC (see §3.4) and average time spent by workers and driver on unloading material on site measured on reference tasks (without kitting) in the AUREA project | 1,572h (10% of working time) |
| Waiting time due to missing material | Estimated per working day based on a sample of measures on site for (3% of working time) reference tasks | 480h |
Empty trips and material handling between storage zone or delivery zone and workspace

| Material move and time lost looking for material at the workspace | Estimated per task based on a sample of measures on site with kitting and without |
| Cleaning and waste elimination | Not measured (no effect expected with this setup) |

### 3.3. Economic impact

The overall cost calculation is presented in figure 7, more on that can be found in [10]. The cost model includes:

- **A1-left (with CCC)** is the actual arrangement between General Contractor and TPL operator. It covers every transport, storage and handling costs from the operator. An additional cost for the prolonged storage during Covid lockdown was also paid and identified separately in the cost breakdown (no estimation of equivalent cost of this Covid impact could be integrated in the cost estimations without CCC because of the unexpected nature of such costs).

- **Transportation成本 from supplier to the CCC are represented in A2 (left). The direct logistic cost without CCC (A1-right) is the overall transportation costs from suppliers to the site based on the estimated delivery scenario calculated with the subcontractors on a weekly basis considering their usual delivery habits, the actual needs on site and the delivery constraints on site (storage capacity and leverage equipment availability). This delivery scenario is also used for environmental impact calculations and presented in §3.4.

- **B1** is the management costs for both GC and subcontractors, based on measured time spent by managers on a sample of tasks with and without kitting. It was decreased by 15%, but from a General Contractor the most noticeable change was in the nature of these activities, since time usually spent on contingency management, reception of trucks and inventories were replaced by planning and specification of the deliveries that can be more easily anticipated and spread over a day. This will be further discussed from a GC perspective in §4.2.

- **B2** represents the avoided congestion and equipment use in relation with the lift. A total of 855h of lift availability during working hours was estimated at working times where at least 1 or several working crews were waiting for the lift.

- **B3 (right)** represents the economic gain of the overall productivity improvement for the whole project.

- The economic impacts (for the subcontractors) of the Non-Value Adding time described in table 1 are represented in B4 (right). Corresponding outsourced activities in the case with CCC and kitting are included in A1.
The calculations indicate that the economic impact of traditional logistics for this project would have been at least 13.3% of the turnover for the activities. In the experimental context of this project a 39% reduction of this cost is estimated and would represent a 5% cost reduction. A translation of this cost reduction in actual margin for all stakeholders a proper gainsharing is needed. Figure 7-right shows cost breakdown between subcontractor and General Contractor before any negotiation based on this cost model. The TPL model implemented in this study was driven and financed by the General Contractor, but it appears to mostly benefit the subcontractors. In the context of this project, a total 3.6% price cut was negotiated between stakeholders, which covered 72% of the costs of TPL.

3.4. Environmental impact

3.4.1. Number of deliveries and load factor. According to research methodology (§2.1), the number of deliveries that would have been needed to transport the same material to the site was estimated on a bi-weekly basis with each subcontractor based on the actual material needs of the site, available storage space and delivery timeslots (lift availability) and based on their own transportation means and habits. The overall number of deliveries in the cases with CCC and without is displayed in fig.8. Overall, 49 deliveries arrived on site (coming from the CCC) when calculations show that 144 deliveries on site would have needed with traditional logistics. Accordingly, the number of trucks entering the city was reduced by 66%. As expected by the theoretical model, the CCC implementation enabled most subcontractors to deliver “full truck” at the CCC instead of having smaller deliveries and complex roundtrips to the site.

Figure 7. Economic details with CCC and without CCC, and distribution of the cost.

Figure 8. Number of deliveries and distances with and without CCC.
Using the digital platform, the number of pallets and the truck’s capacity were known for each delivery from the CCC to the site. Thus, load factors could be monitored and is displayed in Figure 12: the average load factor was 75%. If the exceptional Covid situation of late March and April 2020 is ignored, load factors come close to 80%, which was considered much higher than usual deliveries on construction sites by the General Contractor. The low value (47%) in December 2019 demonstrate that the system is still vulnerable to human mistakes. This will be further discussed in §4.1.6.

Figure 9. Load factors.

3.4.2 Carbon footprint. Based on the number and categories of trucks observed (case with CCC) or estimated (case without CCC) and knowing the trucks’ points of departure, the CO₂ emissions related to the transport of the material could be calculated. These calculations show an overall 46% reduction in CO₂ emissions (fig. 10). The detailed values for each subcontractor are also available in fig. 10. While the overall reduction matches expectations from the literature and comforts the potential of the consolidated construction logistics model for environmental impact reduction, it also appears that the impact was minimal or even negative in some cases. These cases will be discussed in §4.1.1.

Figure 10. Energy consumption and CO₂ emissions.

4. Discussions and conclusion

4.1. Discussions

4.1.1. The potential for a sectorial approach. From a General Contractor’s perspective, these results are promising and should be scaled up at the whole sector. Investment or support by public institutions or entrepreneurial groups could accelerate the development of this model and generate more volume. This would mechanically reduce costs for all clients and stakeholders, as fixed costs (especially related to the warehouse) would be spread over a much higher number of clients. This would allow more flexibility in the choice of the delivery mean and space for last-minute optimisations in case of last-minute changes and lead to further environmental impact with less transportations and smaller distance travelled between CCC(s) and sites.
4.1.2. Supply chain integration and partnerships. As shown in §3.1.3, during the experimentation, suppliers prepared “pre-kits” and were able to adapt to this new system. The earlier suppliers were involved, the more costs were reduced. This was considered a practical example of supply chain integration and could be strengthened by more data integration and interoperability. Moreover, the CCC could be used as an off-site workspace where elements could be assembled. Increasing off-site pre-assembly would further increase the exchange between the General Contractor and the logistician. As a consequence, the CCC model can support the development of off-site and stronger partnerships amongst the supply chain.

4.1.3. TPL or Internalisation of logistics? A CCC could be self-operated by a contractor (especially a General Contractor). In this experiment, the corresponding costs of a self-operated CCC were calculated and the result was about twice the price of the current TPL agreement. Accordingly, the TPL was a clear winner in the current context. For General Contractor, if volumes were to be higher according to §4.1.1, if some value adding operation were outsourced according to §4.1.2, and if additional services were investigated according to §4.1.5, the strategic relevance of the integration of consolidated logistics into core business activities might be reconsidered.

4.1.4. Human value. In addition to improving working conditions on site for both workers and managers, this new logistics paradigm made planning discussion more meaningful and impactful, as they had a direct impact on the next week’s delivery. For the subcontractor being involved, transparent and open meant having the right material where needed the week after. For the General Contractor, this helped a lot in structuring collaborative discussions with subcontractors and setting up a win-win relationship with them. Problems could still happen, but the information was known earlier according to managers, and could be managed collaboratively. Consequently, this improved the integration of newcomers and the training of junior managers.

4.1.5. Reverse logistics. Empty return trips should be eliminated through the integration of material waste. These materials should be collected as close as possible to its source (i.e. the workstation), data should be available in real time in order to define roundtrips accordingly. This would be part of a new circular economy dynamic.

4.1.6. ICT and Digital Twin. Whereas the digital platform was already key for this new process, the points discussed above would increase the complexity of decisions and the need for data from distributed sources, especially if the same model were to be applied to multi-client situations from several companies. This would need for the CCC’s digital platform to manage siloed client’s data in real time and perform multi-site optimisations. This is a relevant use case for a Construction Digital Twin. This could reduce the risk for human mistakes observed in figure 9. In addition, the control of the entire life cycle of the building includes a growing need for information, particularly during the building use, deconstruction and recycling phases. A detailed product management platform could allow to integrate such data according to proper data templates towards further BIM uses.

4.2. Limitations and conclusion
The focus being to demonstrate feasibility in a new context (first time in the country), this study is limited in scope. Further data from more cases is needed. Moreover, productivity and planning impacts could only be assessed based on sample of measures on sites and the model of costs proposed for impacts on site should be applied in other studies to confirm the authors’ findings. Even if subcontractors were closely involved, this study was still conducted and mostly analysed from a General Contractor’s perspective. Further studies should adopt a supply chain perspective and demonstrate the overall impact of CCC from a subcontractor’s perspective. Lastly the environmental impact studied were solely focused on carbon footprint of the transport. Other impacts on the use of material or overall energy consumption on site might be possible and should be taken into account.
Despite these limitations and a suboptimal context (a multi-site case would offer more volume and allowed better load factors), the case study demonstrated a strong adherence from both the General Contractor and subcontractors for the consolidated logistics model. As a consequence, authors believe that this paradigm is a relevant and applicable solution to reduce environmental impacts of the construction sector while improving the economic performance and driving all stakeholders towards innovative practices on site.

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