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METHOD FOR ESTIMATING AND PLANNING CARBON EMISSIONS

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ABSTRACT

With a growing focus on reducing greenhouse gas (GHG) emissions throughout the entirety of a building´s lifecycle, it is necessary to analyze the often-overlooked construction phase, where, besides waste generation, heating, drying, lighting, and process electricity, both equipment and human labor contribute to emission levels.

Building on the Location-Based Management System (LBMS) theory, this paper quantifies emissions from construction machinery and human activities, linking those to specific location tasks. Applied to several case studies and scenarios, including large-scale residential and commercial projects, the approach demonstrated the potential for identifying and reducing greenhouse gas (GHG) emissions.

Findings highlight the necessity of aligning planned schedules with emission targets, suggesting that this integrated quantification method is crucial for compliance with upcoming climate goals and for developing effective emission reduction strategies and technologies in the construction industry, in alignment with 2050 regulatory milestones and EN 15978.

KEYWORDS

Location-based Management System (LBMS), Takt Planning (TP), environment, greenhouse gas emissions (GHG), planning

INTRODUCTION

Although emissions from material production, transportation, and building operations have long been addressed within Life Cycle Assessments (LCA), the quantification of machinery and human resource emissions in stage A5 of the construction industry has historically received less focus. This has resulted in a lack of scientific data on the topic (U.S. Dept. of Energy, 2024).

Early Life Cycle Assessments (LCAs) were primarily developed for manufacturing and production processes, as they were applied to standardized estimates (Hemmati et al., 2023). A5 emissions were often not addressed since they are complex and challenging to accurately measure on-site due to their variability and ever-changing energy demands (Weigert et al., 2022).

Recently, the construction industry has been focusing more on A5 emissions due to increased environmental regulations and advancements in data collection technologies (Wandahl et al., 2021). This shift places greater emphasis on quantifying different sources of energy consumption during the construction phase, including machinery fuel consumption, idle

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times, and energy-intensive human-executed activities. However, official methods for quantifying these emission contributors are still in progress. These current developments underscore the need for new methods and approaches to integrate A5 stage calculations for a more precise LCA quantification (Slosharek et al., 2021).

Quantifying all A5 emission contributors is increasingly essential for construction companies to meet the rising sustainability standards, which require more detailed assessments of environmental impact. By analyzing how emissions are measured and impacted by project changes (whether those are regarding the duration of schedules or resources), projects can find a method to better align with climate targets and regulations, such as those set by the Paris Agreement and the 2050 carbon neutrality goals (Pikas et al., 2024).

From the perspective of construction project management, understanding how A5 emissions are impacted provides a clearer view of optimization processes. It facilitates the identification of high-emission activities, enabling informed choices about machinery, equipment, scheduling, and resource allocation. This helps reduce energy and fuel consumption. Enhanced emission tracking also strengthens accountability and transparency, as calculated data support the results.

The author's previous research (Pedersen et al., 2024) on quantifying carbon emissions in the construction phase demonstrated how Lean methods, such as Location-based Scheduling and Takt Time Planning, were crucial in optimizing energy consumption during the construction phase. The research lacked focus on processes and resource usage during the construction phase. Therefore, this is now considered with this improved and more complete methodology. The paper aims to test the applicability of the methodology.

METHOD

Following Yin´s (2003) methodology, this paper presents exploratory case studies. This research approach was selected because it allowed the authors to examine a phenomenon with limited prior research, specifically machinery and human resource-induced CO_2 emissions during the construction phase. The focus of the study is to understand how changes in construction schedules or resource allocation affect on-site emission levels, whether positively or negatively.

A literature review serves as a good starting point for any research; however, unfortunately, the topic of this study is not widely discussed within the construction literature yet. Although it is indicated that construction emissions could account for as much as 30% of a project´s embodied carbon (Pearson & Taylor, 2023), there is still a lack of data on specific values.

Research linking GHG emissions to the schedule is scarce (Lim et al., 2016), and obtaining precise data is challenging. In addition, many studies often assume that the energy consumption in A5 is limited and, therefore, negligible, or underestimate its impact (Hendrickson & Horvath, 2000; Lemay, 2011). Therefore, this paper builds on the author's previous research on A5 emissions, calculations detailed in the paper "Quantifying and planning carbon emissions in construction with Location-Based Scheduling" (Pedersen et al., 2024). A thorough introduction to LBMS can be found in Kenley and Seppänen (2009).

To achieve a comprehensive result, it is essential to include as many A5 phase contributors as possible in the calculation. Calculations related to heating, drying, lighting, and site processes are based on the above-identified source, serving as the basis for the current calculation, which also includes emissions from machinery and human resources (see Equation 1 below). In the end, the two parts of the equation, one quantifying site services, the other site temporary services, machinery, and manpower emissions, come together to form an overall number of emissions for the project's A5 phase.

$$Q = \sum E_{electric} * I + E_{fuel} * EF + Q_{manpower} \quad (1)$$

Where:

Q = total quantity of CO_2 emissions in phase A5 [$kgCO_2$]
E = energy consumption for the various contributors, as a whole named $E_{construction}$ [kWh]
I = CO_2 intensity of the produced electricity [$kgCO_2$/kWh]
EF = Emission factor (dependent on the type of fuel)
$Q_{manpower}$ = Emission from people on-site (including transport to the site) [$kgCO_2$]

Energy-consuming resources are split into the following contributors:

$$E_{construction} = E_{heating} + E_{drying} + E_{lighting} + E_{sheds} + E_{machinery} \quad (2)$$

Where:

$E_{construction}$ = Energy consumption in phase A5 [kWh]
$E_{heating}$ = Energy consumption for heating of building [kWh]
E_{drying} = Energy consumption for drying of building [kWh]
$E_{lighting}$ = Energy consumption for lighting of the site [kWh]
E_{sheds}= Energy consumption for accommodating temporary facilities for workers [kWh]
$E_{machinery}$ = Energy consumption for machinery [kWh]

The CO_2 emissions from manpower are estimated according to Equation 3.

$$Q_{manpower} = N_{hours} * N_{manpower} * C_{manpower} \quad (3)$$

The emissions are allocated to account for seasonal variations and various base consumption factors, as listed in Equations 4-8.

$$E_{heating} = N_{wdays} * A * C_{heating} \quad (4)$$

$$E_{drying} = N_{wdays} * A * C_{drying} \quad (5)$$

$$E_{lighting} = Day * A * C_{lighting} \quad (6)$$

$$E_{sheds} = N_{wdays} * A * C_{heating} + N_{days} * A * C_{lighting} \quad (7)$$

$$E_{machinery} = N_{hours} * N_{machinery} * C_{machinery} * U \quad (8)$$

Where:

N_{wdays} = Number of winter days [days]
A =Area per location [m^2]
$C_{heating}$ = Base consumption for heating of building / day =86 kWh/m^2
C_{drying} = Base consumption for drying of building / day = 17 kWh/m^2
$C_{lighting}$ = Base consumption for lightning / day = 27 kWh/m^2
$C_{manpower}$ = Base consumption for manpower [$kgCO_2$]
$C_{machinery}$ = Base consumption for machinery [liters of fuel / kWh electricity]
Day = Construction time [days]
N_{days} = Number of working days [days]
N_{hours} = Number of work hours [hours]
$N_{manpower}$ = Number of manpower
$N_{machinery}$ = Number of machineries
U = Usage factor, for simplification set to [0.6]

Several factors influence the calculation of emissions in phase A5. These include parameters related to the construction process, site characteristics, energy consumption, type of machinery used, and the overall project timeline. The key contributors are as follows:

- **Project-specific variables:**
    a. **Number of winter days (N_{wdays}):** The total number of days falling within the defined winter period, impacting heating energy consumption. For this study, the winter period is defined as spanning from October 1st to March 31st. This is particularly relevant in cold-climate regions, such as the Nordic countries; in other parts of the world, cooling should be considered instead.
    b. **Area per location (A):** Since we are employing the theory of LBMS in this research, we have the possibility of extracting tasks from locations separately and quantifying them; therefore, value A is measured in square meters.
    c. **Construction time (Day)**: The total duration of the project, determined by the start date of the first activity and the end date of the last activity. This determines the number of working days requiring energy for lightning and construction processes.
    d. **Number of working days (N_{days}):** The total number of days within the construction that involve active work.
    e. **Number of work hours (N_{hours}):** The cumulative work hours during the construction period.
    f. **Number of workers ($N_{manpower}$) and Number of machines ($N_{machinery}$):** these define the intensity of on-site resources.
    g. **Usage factor (U):** Represents the average percentage of time machinery and resources are actively utilized. In this research, the usage factor is estimated at 60%, but can range between 40 and 80%, depending on the specific activities on-site (For Construction Pros, 2009).
- **Energy and emission factors:**
    h. **CO_2 intensity of produced electricity (I):** The carbon intensity, measured in kg CO_2/kWh, varies by country and energy production method.
    i. **Emission factor (EF):** The type of fuel used influences the carbon output from machinery.
- **Construction site conditions:**
    j. **Full construction period per location:** The start and end dates for activities within each site location determine the operational days for lighting and processing electricity.
    k. **Winter periods:** Identify the number of winter periods within the project timeline, as they significantly impact heating energy consumption.
    l. **Idle periods:** gaps during the construction period when no work is conducted, requiring analysis of energy waste. These idle periods necessitate segmenting the location into multiple work phases.
    m. **Type of heating:** The heating method employed, such as district heating or diesel engines and calorifiers, is crucial for calculating emissions.
    n. **Energy installation type:** Determining whether electricity and heating systems are shared across the site or allocated to individual buildings. Proper segmentation ensures that energy is not wasted in unoccupied buildings.

In the following sections, the results and findings of applying the method to real project data are presented and described.

CASE STUDIES AND RESULTS

The research examines two distinct cases, a real-life case and a fictional one. Each presented with preconditions, findings, and conclusions. Ensuring confidentiality, project names, and detailed information are withheld. These cases encompass various building types, yet all utilize principles of LBMS. The construction schedules were created using the Tactplan software (www.tactplan.com), and resources were assigned to all activities, as illustrated in Figure 1. Post-processing in Excel was then performed on the schedules to calculate emissions.

Table 1 below contain the emission factor values used for calculating emissions from different types of machinery. The emission factor for electricity varies depending on the country of use, as each country has various methods of producing energy, some of which are more sustainable than others. The number in this table refers to Denmark´s carbon intensity of electricity, according to the Our World in Data website (n.d.). The numbers for gasoline and diesel, however, are universal (Li & Chen, 2016).

Table 1: Emission factors (EF) for different machinery fuel types

Fuel type	Emission factor
Electricity [kWh]	0.152
Gasoline [kg]	3.51
Diesel [kg]	3.68

Table 2 contains the consumption values used to calculate emissions associated with machinery used on-site. Most of these numbers, just like the previously introduced emission factors, stem from Li & Chen (2016).

Table 2: Fuel consumption of various machinery (Li & Chen, 2016)

Machine	Consumption per hour	Measurement
Concrete mixer	29.33	kWh
Excavator	7.88	kg (diesel)
Concrete pump	25.91	kWh
Concrete vibrator	0.50	kWh
Backhoe loader	8.15	kg (diesel)
Dump truck	5.82	kg (diesel)
Compactor	2.08	kWh
Mobile crane	7.50	kWh
Forklift	6.69	kg (gasoline)
Façade installation crane	24.78	kWh
Telescopic handler	6.69	kg (gasoline)
Hoists	5.47	kWh
Power drill	5.00	kWh
Welding equipment	14.88	kWh
Cutting equipment	4.01	kWh
Nail gun	5.45	kWh
Saw	3.00	kWh
Mortar mixer	29.33	kWh
Conduit bender and threaders	1.29	kWh
Cable pullers	1.29	kWh
Power screwdriver	5.45	kWh
Rotary cutter	4.01	kWh

Paint sprayer	5.45	kWh
Pipe threader, cutter, bender	1.29	kWh
Sander	1.29	kWh
Lifting equipment	7.42	kWh
Tower crane	24.78	kWh
Core drill	3.20	kWh
Concrete grinder	5.00	kWh
Concrete saw	4.01	kWh
Rebar bender	1.60	kWh
Rebar cutter	4.01	kWh
Rebar straightener	1.86	kWh
Industrial vacuum	5.00	kWh
Floor grinder	2.20	kWh
Tile cutter	3.00	kWh

The overall emission amount in every case study is calculated by aggregating the emissions caused by heating, drying, lighting, processes, machinery, and manpower. The current plan does not include any supplementary drying equipment, as the temperature-sensitive internal processes align with the internal heating system. This results in an E_{drying} value of 0.2, which can therefore be considered negligible.

CASE STUDY A – 5,000 M2 NEW OFFICE

This case is the only fictional one within this research. It entails office construction, where LBMS is utilized in planning from the outset. The location-based schedule for the project is shown in Figure 1, as a direct snapshot from the web-based scheduling tool www.tactplan.com. It shows both the time and location of the individual tasks and the allocated resources. The results from the case study are presented in Table 3 on the next page.

Figure 1: Location-based Schedule for Case Study A. The extra purple task from start to end has been added for extracting general site resources.

Preconditions

LBMS is integrated into the project from the beginning, encompassing both the structures, closing, and internal works. CO_2 emission calculations cover the entire project, from March 5, 2024, to June 27, 2025, in the original scenario (Scenario 1).

Site services, such as heating, drying, and lighting, are affected in each scenario according to the project's duration and timeframe.

The number of workers also predominantly affects the number of square meters of sheds they need, which accommodates them with resting, eating, showering, and getting a ready place. This area affects the overall number of kWh required for heating and lighting during the project.

Scenario 1

Construction tasks are analysed with an appropriate number of resources, including both machinery and human resources.

Scenario 2

Lowering the number of resources to an absolute minimum, therefore executing the same project within a longer duration. The point of the scenario is to determine if the CO_2 emission savings resulting from resource conservation justify a longer schedule. Ultimately, the goal is to determine whether site services or resources are more beneficial to spare from a sustainability perspective.

Scenario 3

Doubling the number of resources compared to the original Scenario 1. The goal is the same as in the previous scenario.

Conclusions

Being able to adjust the number of resources and, therefore, influence the duration of projects presents an opportunity to make the most advantageous project-specific decisions. Within these three scenarios, we can identify the highest difference of 60.72% tons of CO_2 emissions as shown in Table 3.

Table 3: Results for Case Study A

Scenario 1			Scenario 2			Scenario 3		
CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]	CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]	CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]
101.34	20.27	479	127.84	25.57	629	79.03	15.81	402

CASE STUDY B – 17,700 M2 NEW RESIDENTIAL

A real-life case of a new residential building, where the schedule has been done the same as in Case A, and illustrated in Figure 1. The results are listed in Table 4.

Preconditions

Similarly to Case study A, LBMS is implemented from the beginning to the end of the project.

Scenarios 1, 2 and 3

These scenarios are differentiated in the same way as Case study A (differing in number of resources, therefore project duration).

Conclusions

Similar to Case Study A, the findings indicate a significant correlation between the number of resources used on-site and the project duration, see the table below:

Table 4: Results for Case Study B

Scenario 1			Scenario 2			Scenario 3		
CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]	CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]	CO_2 tons	CO_2 kg/m^2*year for 50 years	Project length [days]
231.11	13.06	400	361.07	20.40	545	243.43	13.75	273

CURRENT LIMITATIONS OF THE METHOD

The approach is based on data derived from reports that are at least five years old, which may lead to an underrepresentation of efficiency improvements in energy and fuel usage. Nevertheless, the method devised facilitates the rapid modification of parameters, enabling the automatic recalibration of results based on the most current information.

The difficulty in acquiring current and trustworthy data necessitates collaboration among building owners, equipment suppliers, management teams, and contractors. More in-depth research could be conducted with participants who are prepared to monitor, analyse, and share their consumption statistics.

Such statistics could be: 1) kWh used for electricity on site, 2) kWh used for heating on site, 3) kWh used for warm water, 4) kWh used for heating the temporary offices, 5) kWh used for heating the changing rooms for workers, and 5) Emissions from diesel-, gasoline- and electricity powered machinery, 6) number of human resources present on the building site in various stages of the project.

Another constraint of the study is that the computations are based on average values derived from various project types. As suggested by Pedersen et al. (2024), considering similar research, a more effective methodology would involve establishing a comprehensive database of projects, enabling the selection of the most comparable project according to the specific parameters outlined. This would enhance the correlation between historical projects and new estimations. Nevertheless, such dependable data is not presently available.

DISCUSSION

The findings derived from the case studies and analysed scenarios indicate that the quantification method applies to a range of contexts and situations.

Relationship between human resources and machinery

The interplay between human resources and machinery is a critical factor in A5 emissions. Human activity directly influences emissions through energy consumption for temporary facilities and indirectly via operational decisions that affect machinery utilization. For instance, workforce size impacts the demand for temporary site services, such as heating and lighting for accommodations. Concurrently, the operational efficiency of machinery often depends of skilled human intervention. A balanced allocation of manpower and machinery, as demonstrated in the case studies, is essential for optimizing emissions. Scenarios with minimal resources tend to extend project timelines, potentially increasing emissions from temporary services, whereas scenarios with excess resources heighten machinery usage and associated emissions. Therefore, finding the optimal synergy between these elements is vital for sustainable construction practices.

A5 stage contributors as a whole

The A5 stage encompasses multiple emission sources, including machinery, human labour, and site services such as heating, drying, and lighting. Quantifying these contributors requires a comprehensive approach integrating diverse factors, such as project-specific variables, energy consumption patterns, and country-specific emission factors. For example, machinery emissions depend on fuel type, efficiency, and utilization rates, while human resources emissions stem from site efficiency, accommodations, and energy demands. The presented formula (Construction) consolidates these contributors, providing a structured framework for assessing total emissions. However, gaps remain in accurately modelling less tangible contributors, such as idle time and material waste, underscoring the need for future development.

Comparison between resource numbers and project length

The relationship between resource allocation and project duration is a decisive factor in determining A5 emissions. Case studies reveal that scenarios with minimal resources often result in extended project timelines, leading to increased emissions from prolonged site services. On the other hand, scenarios with abundant resources shorten project timelines but increase emissions from the intensified use of machinery and manpower. For example, in Case Study A, the difference in emissions between the least and most resource-intensive scenarios was 60.72%, highlighting the trade-offs involved. This comparison highlights the importance of context-specific decision-making, where resource allocation is tailored to strike a balance among emissions, project duration, and cost efficiency.

Human resources – Temporary services tied to emissions

Temporary services for human resources, such as heating and lighting accommodations, also contribute to A5 emissions. These services are directly proportional to the size of the workforce and the duration of their on-site presence. As observed in the case studies, larger workforce numbers increase the demand for energy-intensive facilities, raising overall emissions. Strategies to mitigate these impacts include optimizing workforce scheduling from the beginning of the design phase, therefore improving energy efficiency in temporary accommodations, and exploring renewable energy sources for site services. Integrating these measures can substantially reduce the carbon footprint of human resources in construction projects.

Importance of emission factors

As mentioned earlier, in relation to the emission factors presented in Table 1, the carbon intensity value of electricity should apply to the specified country. Since some countries are ahead of others in renewable energy practices and, therefore, have a lower energy emission factor, using a non-project-relevant value could cause the emission calculations to fluctuate significantly, no longer accurately reflecting reality. This can lead to deep-seated issues with project regulations, regulatory compliance, and laws.

POSSIBILITIES FOR FUTURE DEVELOPMENT

Idle time involvement

Addressing the idle time – periods when machinery or resources are not in active use – is critical for reducing emissions. Improved scheduling and resource management, facilitated by methods like LBMS, can minimize idle periods and associated energy waste. Incorporating real-time tracking systems to monitor resource utilization could further enhance efficiency.

Material waste involvement

Material waste contributes indirectly to emissions through increased energy demands for production, installation, and disposal. Future research should focus on integrating waste reduction strategies into A5 emission models. This includes designing for material efficiency, recycling, and utilizing modular construction techniques. Temporary equipment, such as scaffolding or temporary closures, is also a significant contributor to waste and emissions and should be included in the estimations.

Software integration for automated calculation

The development of location-based construction schedules and resource allocation can be done efficiently with modern software, such as Tactplan.com, used in this research. However, the emission calculations involved in this study are labour-intensive and conducted using spreadsheets. In the future, they should be incorporated into a scheduling tool using the LBMS method for a faster estimate. This tool would be capable of retrieving basic project information, including activity start and end dates, recognizing winter seasons, and implementing baseline values and factors. Additionally, resources such as manpower and machinery can be assigned to specific tasks to achieve a comprehensive and cohesive solution. These features could enable an innovative, fast, and real-time decision-making tool for the construction industry, thereby enhancing its contribution to sustainability initiatives.

CONCLUSIONS

The findings of this study highlight the crucial importance of incorporating carbon emission considerations into the construction planning process, particularly during the A5 stage. By linking emissions to specific tasks and construction schedules, the research demonstrates the profound impact of project timelines and resource allocation on overall emissions. A key takeaway is the necessity of shifting the focus from reactive documentation of emissions to proactive planning, emphasizing the need for early-stage integration of emission goals into scheduling frameworks.

The case studies reveal that changes in construction schedules have a significant impact on A5 emissions. The prevalent issue of delayed or failed schedules exacerbates emissions, underscoring the urgent need for improved project planning methods, such as Lean construction principles and Location-Based Management Systems (LBMS). Moreover, while compressed schedules might save time, they often fail to optimize emissions due to reduced site efficiency and increased resource intensity. This highlights the importance of balancing time, resources, and emissions in project planning.

To address these challenges, the construction industry must adopt a more systematic approach to scheduling optimization and integrate advanced tools to reduce inefficiencies. Future efforts should also focus on enhancing workforce efficiency and refining emission modelling techniques to ensure compliance with ambitious climate targets.

REFERENCES

Our World in Data. (n.d.). *Carbon intensity of electricity generation*. Retrieved May 8, 2024, from https://ourworldindata.org/grapher/carbon-intensity-electricity?tab=chart&country=~DNK

Hemmati, M., Messadi, T., & Gu, H. (2023). Life cycle assessment of the construction process in a mass timber structure. *Sustainability*, *16*(1), 262. https://doi.org/10.3390/su16010262

Hendrickson, C. and Horvath, A. (2000). Resource use and environmental emissions of the U.S. construction sectors. *Journal of Construction Engineering and Management*, [e-journal] 126(1), pp.38-44. https://doi.org/10.1061/(ASCE)0733-9364(2000)126:1(38)

Kenley, R & Seppänen, O. (2009): *Location-Based Management for Construction: Planning, scheduling and control***.** Taylor & Francis e-library.

Lim, T., Gwak, H. and Kim, B. (2016). Integrated carbon emission estimation method for construction operation and project scheduling. *KSCE Journal of Civil Engineering* 20, pp.1211–20. https://doi.org/10.1007/s12205-015-0360-x

Li, L., & Chen, K. (2016). Quantitative assessment of carbon dioxide emissions in construction projects: A case study in Shenzhen. *Journal of Cleaner Production*, *141*, 394–408. https://doi.org/10.1016/j.jclepro.2016.09.134

U.S. Department of Energy (2024). *Embodied Carbon Reduction in New Construction: Reference Guide*. https://doi.org/10.2172/2336716

Pearson, C. & Taylor, E. (2023). The Missing Embodied Carbon Link: Construction. *BuildingGreen*. https://www.buildinggreen.com/feature/missing-embodied-carbon-link-construction

Pedersen, K. B., Stefankovics, G., Nachev, S. P., & Wandahl, S. (2024). Quantifying and planning carbon emissions in construction with Location-Based Scheduling. *Annual Conference of the International Group for Lean Construction*, 416–427. https://doi.org/10.24928/2024/0175

Pikas, E., Lõhmus, R., Koskela, L., Tetik, M., & Vendel, K. (2024). Carbon emissions of construction operations in a cold climate. *Annual Conference of the International Group for Lean Construction*, 1063–1073. https://doi.org/10.24928/2024/0228

Slosharek, B., Dlouhy, J., Schneider-Marin, P. & Lang, W. (2021). Takting the Sustainability of Construction Processes: An Environmental Assessment Method, *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC)*, 902-912. doi.org/10.24928/2021/0198

For Construction Pros (2009). Utilization 101. Retrieved May 15, 2025, from https://www.forconstructionpros.com/rental/article/10116913/utilization-101

Wandahl, S., Pérez, C. T., Salling, S., Neve, H., Lerche, J., and Petersen, S. (2021). The Impact of Construction Labour Productivity on the Renovation Wave. *Constr. Econ. Build.*, 21 (3). https://doi.org/10.5130/AJCEB.v21i3.7688

Weigert, M., Melnyk, O., Winkler, L., and Raab, J. (2022). Carbon Emissions of Construction Processes on Urban Construction Sites. *Sustainability,* 14 (19): 12947. https://doi.org/10.3390/su141912947

Yin, R.K. (2003). *Case study research: Design and methods.* Thousand Oaks, CA: Sage.