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STRATEGIC LEVERS FOR PREFABRICATION IN CONSTRUCTION: AN ECONOMIC CASE STUDY

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ABSTRACT

The prefabrication industry is expected to grow and offer significant benefits to the construction industry, including improved efficiency, cost savings, quality and sustainability. Despite these benefits, there is a gap in the literature regarding the strategic levers that determine the optimal level of prefabrication. This study aims to investigate three levels of prefabrication (L1: brick walls, L2: brick walls with electrical installations and L3: brick walls with electrical installations and plastering) from an economic point of view. Levers from the literature were validated and supplemented based on an expert workshop with a small to medium-sized supplier of prefabricated elements and construction service provider in southern Germany. The economic feasibility was assessed using sensitivity analysis, focusing on cost drivers for organizational effort and increased efficiency. The results showed that higher levels of prefabrication (L2 and L3) lead to significant efficiency gains, especially in the best-case scenario. Organizational effort increases with the level of prefabrication, but at L3, efficiency improvements outweigh complexity, reducing costs such as material savings and mitigation of weather-related disruptions. Prefabrication, when strategically integrated, not only achieves the same goals as lean construction activities such as workflow efficiency and waste minimization, but the economic benefits increase with the level of prefabrication. This means that, under stable conditions, a high level of prefabrication is economically viable.

KEYWORDS

Prefabrication, Production Processes, Level, Profitability, Case Study

INTRODUCTION

The prefabrication industry is expected to grow at a compound annual growth rate (CAGR) of 8.72% from 2023 to 2028 (Technavio, undated). The implementation of industrial prefabrication in the construction industry presents a multitude of substantial benefits. These include enhanced efficiency through the processes of pre-production and standardization, cost savings resulting from material optimization and economies of scale, and improved quality using controlled production conditions (Mawdesly and Long, 2002; Ballard and Arbulu, 2004; Bjornfot and Stehn, 2004). Furthermore, prefabrication allows for the separation of construction from the effects of inclement weather, enhances safety on construction sites, encourages sustainability by reducing material consumption and emissions, and facilitates innovation

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through the utilization of contemporary technologies and modular construction methods. Nevertheless, it is important to acknowledge the potential drawbacks of prefabrication, which must be considered when evaluating its merits (Koskela, 2003).

It is particularly noteworthy that the integration of industrial prefabrication with lean construction is based on a common goal of minimizing waste and improving efficiency (Mawdesly and Long, 2002; Ballard and Arbulu, 2004; Larsson and Simonsson, 2012). The aims are achieved through the implementation of standardized production processes, as well as the prioritization of just-in-time deliveries and the elimination of non-value-adding activities, which are fundamental tenets of the lean construction approach. Together, they serve to enhance quality and foster collaboration, thereby driving continuous optimization within the construction process.

A pivotal concept that enables the transition between prefabrication and lean construction activities (on-site) is the Customer Order Decoupling Point (CODP). The CODP represents the point in the value chain where customer requirements are clearly defined, marking the transition from a push system, whereby prefabricated products are manufactured to stock with time buffers to accommodate uncertainties, to a pull system, in which processes are more flexibly tailored to customer specifications. Rather than a strict transition from prefabrication to lean construction, CODP serves as a dynamic interface that ensures prefabrication and lean construction principles function concurrently, balancing production efficiency with on-site adaptability. (Hoekstra and Romme, 1992) The CODP thus represents a crucial transition point, marking the shift from prefabrication to lean construction and facilitating the seamless integration of these two methodologies.

However, there is considerable diversity in the approaches adopted by construction companies regarding horizontal prefabrication. Some concentrate their efforts on the fabrication of shell construction elements (e.g., WMM AG), while others pursue a more integrated approach to interior construction (e.g., ecoworks GmbH). Scientific studies such as Aghasizadeh (2022) and Zhou (2022) analyse the economics of prefabrication but focus on a single level. Aghasizadeh uses cost-benefit analysis (CBA) and life cycle costing (LCC), noting cost variability due to design. Zhou emphasises resource savings, with environmental benefits outweighing economic gains. External factors such as market conditions, labour costs and regulations affect the feasibility of prefabrication, so understanding them is crucial for optimal implementation.

Despite the growing importance of this field, there is a notable gap in scientific research regarding a clear analysis of the strategic levers for defining the optimal point of the COPD or level of prefabrication. The analysis targets a structured, well-defined, and comprehensive examination of the strategic levers that influence the determination of the optimal Customer Order Decoupling Point (CODP) or level of prefabrication. It includes outlining key levers, and a systematic evaluation based in a practical application involving a construction company with expertise in prefabrication. The analysis examines three levels of prefabrication (L1, L2, L3) to identify strategic levers for effective implementation and future research. These levels, chosen for their different levels of complexity, supply chain involvement and local needs, allow for a structured assessment of efficiency, cost and adaptability.

Section 2 identifies and contextualizes relevant studies and levers from the existing literature. Section 3 presents the methodology for conducting an economic comparison of quantifiable levers. The results of the case study on the three prefabrication stages are discussed in Section 4, followed by a summary of key findings and implications for practice and further research in Section 5.

LEVERS IN PREFABRICATION

The literature review identifies and contextualizes levers influencing efficiency and organizational efforts in construction prefabrication. The studies reveal both complementary and contrasting approaches to achieving efficient prefabrication in construction.

Initial Investments: A major cost driver in prefabrication is the high initial investment in digital technologies and infrastructure. A German case study on digital fabrication highlights the transition from traditional methods to automated manufacturing, emphasizing the financial burden of digital implementation but also the long-term benefits of reduced material waste and construction time (Schmidt-Kleespies et al. 2021). Similarly, Knippers et al. (2021) identify automation and robotics as primary cost factors, leading to reduced labor costs and improved scheduling efficiency. Brell-Cokcan & Schmitt (2024) extend this perspective by discussing the role of digital networking in optimizing construction supply chains, although the required infrastructure remains a limiting factor. In Austria, Pibal et al. (2023) emphasize the cost of digital infrastructure while also highlighting digitalization's role in reducing errors and improving affordability.

Logistics and Transportation Costs: Transportation and logistics constitute another significant economic challenge. Rosenberger (2011) identifies transportation costs for large, prefabricated elements as a key barrier to economic efficiency. Similarly, Citaku (2023) and Borosnyai (2018) highlight the financial burden of logistics in hybrid and mass timber construction, respectively, despite the savings associated with precise prefabrication. Lu & Yuan (2013) extend this discussion to offshore prefabrication, underscoring logistics planning as a crucial element in minimizing waste and cost. Furthermore, Tam (2007) stresses early design freezing as a strategy to avoid costly on-site revisions, although this can limit design flexibility and lead to expensive modifications if changes are required later.

Digitalization and Process Optimization: The role of digitalization in reducing costs and improving efficiency is widely acknowledged. Pibal et al. (2023) emphasize digital tools in modular housing to enhance affordability by reducing errors and material waste. Li (2014) highlights technological advancements such as RFID and BIM as key to successful prefabrication when combined with regulatory support. Baghchesaraei (2015) discusses modular standardization as a cost-saving measure that reduces labor costs and shortens assembly times. Lu et al. (2218) take a broader approach, advocating policy incentives and social acceptance as crucial external factors for successful prefabrication adoption.

Material Considerations and Sustainability: While digitalization and logistics are key economic drivers, material considerations also play a role. Wimmer & Hohensinner (2001) focus on renewable materials, which offer long-term energy savings but require higher initial investments. Additionally, they highlight the economic risks associated with fluctuations in material availability, contrasting with other studies that focus more on digitalization and logistics.

The economic feasibility of prefabrication depends on balancing high initial investments with long-term cost savings. However, despite the advantages of prefabrication, adoption barriers such as the investment costs or logistical challenges hinder widespread implementation. Limited quantitative studies on prefabrication, mainly in wood, highlight a research gap. In summary, the reviewed studies identify key levers in prefabrication, which are summarized and logically supplemented in Figure 1. The figure shows how efficiency gains through optimisation, standardisation and technology reduce organisational effort. However, market conditions, regulations and social attitudes influence feasibility and scalability. The disparate foci, ranging from internal process controls to external regulatory and social levers, illustrate that successful prefabrication necessitates a balance between production efficiency and organizational effort, with due consideration of general influences. As customer demand increases and efficiency rises, organizational effort declines. The reviewed levers, particularly those concerning standardization, logistics, and technological advancements, influence the positioning of the Customer Order Decoupling Point (CODP) by determining how prefabrication processes shift between push- and pull-based production systems. These levers optimize prefabrication and strengthen its role in modern construction.

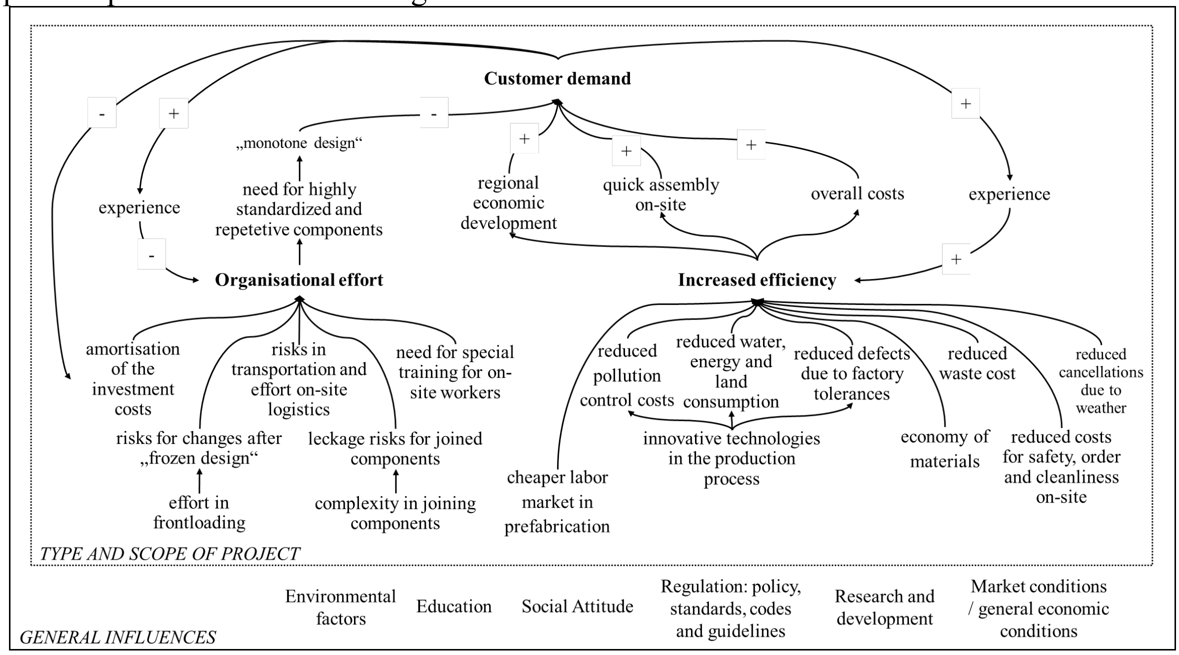

Figure 1: Contextualization of the identified levers for prefabrication according to the literature review

METHODOLOGICAL APPROACH

A single case study approach was chosen to provide an in-depth analysis of prefabrication strategies within a real-world context. While this method allows for detailed insights, its limitations include restricted generalizability and dependence on the specific conditions of the studied company. The case study presents a comparative analysis of three levels of prefabrication. The three levels of prefabrication are as follows: L1 represents a minimal level of prefabrication with prefabricated brick walls, L2 integrates electrical installations to reduce site work, and L3 incorporates finishing processes including both electrical installations and plastering to maximize prefabrication benefits. The selection of these prefabrication levels is based on their distinct complexity, degree of on-site work reduction, and potential cost efficiency. All levels are examined based on the prefabrication line of an industry partner. This partner is a small to medium-sized enterprise operating primarily in southern Germany. Since 2024, in addition to offering both civil and structural construction services, the company has established a prefabrication line dedicated to the industrial production of brick walls. Hence, the company under study functions both as a construction service provider and a supplier of prefabricated elements, integrating production with on-site application. The initial benefits of prefabrication are evident, although they are not yet quantifiable. To further unlock potential, additional levels of prefabrication will be evaluated for a possible strategic expansion. Figure 2 presents a visual representation of the partner's prefabrication facilities. To assess the economic value of the three prefabrication levels, the identified optimization levers (see Figure 1) will be utilized, allowing for a comparison of their respective contributions to economic value.

The calculation of economic efficiency can be approached in two distinct ways: static and dynamic. Static methods, such as CBA, profitability analysis and payback period, average investment-related revenues and expenses over a constant annual value. Dynamic methods, on the other hand, use techniques such as net present value (NPV), annuity and internal rate of return (IRR) to differentiate the timing of cash flows, considering the effects of interest and compounding (Bränzel et al., 2019, p. 236). For the following case study, the static method of sensitivity analysis may be preferable to dynamic methods due to its simplicity and focus on key cost levers such as transportation and production.

Figure 2: Impressions of the prefabrication of brick walls at the industry partner

Sensitivity analysis quickly assesses how variations in critical variables affect overall profitability, without the need to consider complex levers such as the time value of money. It shows when, how and under what conditions assumptions change the outcome, identifies the most economical course of action and highlights the dependency of decisions on initial assumptions without changing the profitability calculation itself (Tian, 2013).

The values for the profitability calculation were determined and estimated to the best of our knowledge in a half-day workshop with the managing director of the company and the head of the prefabrication line. Three distinct scenarios were defined to evaluate the economic feasibility of the prefabrication line for each prefabrication level: worst, average, and best case.

1. Worst Case: This scenario assumes a minimal number of small-scale projects with limited use of prefabricated components. The economic calculation is based on conservative estimates, such as high values for the hours required to address potential defects or higher-than-average material costs. These values represent a situation reflective of an unfavorable economic environment or reduced demand.
2. Best Case: In contrast, the best-case scenario assumes full utilization of the prefabrication line. This is achieved through a high number of projects with extensive use of prefabricated components. The economic feasibility calculation for this scenario incorporates ideal values, such as minimized material costs and significantly reduced time for defect resolution. This scenario reflects an optimal market and operational condition, maximizing the efficiency and profitability of the prefabrication line.
3. Average Case: The average case represents the most realistic scenario, based on moderate values for the number of projects and prefabricated components. This scenario assumes market conditions and operational efficiency that align with industry averages, providing a balanced perspective on potential outcomes.

Table 1 summarizes the assumptions for the three scenarios, specifically focusing on the number of projects and the quantity of prefabricated components. Additionally, it is assumed that, on average, one prefabricated component occupies 10 square meters of area within a construction project.

Quantifiable levers from Figure 1 were used to calculate the scenarios. Table 2 summarizes the used levers. Where available, data from the literature was utilized and critically analysed. Notable references include Wang (2020) and Zhou (2022). Missing values were supplemented during an expert workshop. This process also revealed that certain values from the literature are either irrelevant in practical application or lack available data now. Missing values were classified as non-strategic variables in the economic feasibility calculation, as they are not expected to have a significant impact on the overall results.

Table 1: Scenario assumptions of market situation in the selected construction company

	Worst Case	Average	Best Case
Number of projects per year	30	50	80
Number of parts per project	20	40	50

Table 2: Used levers for the organizational effort and increased efficiency

Organizational effort			Increased efficiency		
Amortization of machine costs	Risks for changes after "frozen design"	Additional effort in joining components	Reduced process costs	Reduced defects	Reduced costs for cleanliness
Amortization for production hall	Risks in transportation	Leakage risks	Reduced water	Reduced waste costs	Reduced cancellations due to weather
Additional effort in frontloading	Special training for workers		economy of materials	Reduced costs for safety	

These variables include:

1. **Additional effort for on-site logistics:** Prefabricated components are either unloaded directly from the truck or stored in transport boxes on-site until assembly. As a result, no additional logistical effort is assumed.
2. **Reduced pollution control costs:** In the context of Germany, this variable is not yet accounted for in economic calculations and thus remains excluded from the analysis.
3. **Reduced land:** Based on prior experiences, it can be assumed that no additional land or space is needed for prefabricated construction.
4. **Reduced energy consumption:** At this stage, no relevant data is available for this variable.
5. **Reduced costs per order:** Like energy consumption, no data is currently available for this lever.

By identifying and excluding these variables, the focus of the analysis remains on parameters that are both measurable and relevant to the economic evaluation of prefabrication processes. This ensures a clear and structured approach to assessing the feasibility of prefabrication at this early stage.

RESULTS FROM THE CASE STUDY

Table 3 presents the result values for organizational effort and improved efficiency across the different scenarios (Worst Case, Average, and Best Case) and levels of prefabrication (L1: Brick Walls, L2: L1 + Electric, L3: L2 + Exterior Plaster). For each scenario and level, the four most influential levers in terms of economic impact are highlighted. The dominant levers vary significantly depending on the scenario and the level of prefabrication. These variations underline the complexity of assessing prefabrication's economic implications and demonstrate how specific variables gain or lose relevance as the depth of prefabrication increases or as different scenarios are considered.

By focusing on these levers, the sensitivity analysis provides a clearer understanding of which parameters are most critical to economic performance under varying conditions. This targeted approach ensures that recommendations can be tailored to specific project scenarios and prefabrication levels, optimizing decision-making in practice.

Table 3: Organizational effort and increased efficiency for the three scenarios (Worst Case, Average, Best Case) in EUR

	Worst Case			**Average**			**Best Case**		
Levers	L1	L2	L3	L1	L2	L3	L1	L2	L3
Organizational effort	348.120	526.680	653.630	320.960	602.880	883.280	167.680	298.120	648.120
Increased efficiency	-36.774	-199.459	-410.243	-438.021	-1.487.765	-2.364.955	-2.032.457	-4.793.523	-6.893.099
Delta	311.346	327.221	243.387	-117.061	-884.885	-1.481.675	-1.864.777	-4.495.403	-6.244.979

ORGANISATIONAL EFFORT

The analysis of organizational effort reveals a significant increase as the level of prefabrication depth and scenario variations progress. In the Worst Case, Level 3 exhibits the highest organizational effort at €653,630, whereas in the Best Case, Level 1 demonstrates the lowest effort at €167,680.

This category exhibits high variability in annual costs depending on specific levers, as shown by the sensitivity analysis. The levers for organizational effort are as follows:

1. **Amortization of Investment Costs (e.g., machinery)**: These costs remain constant across scenarios since they are independent of production utilization rates. For instance, the amortization values for machinery and production facilities remain fixed, contributing €95,000–€97,000 to the overall costs in all scenarios. Knippers et al. (2021), Brell-Cokcan & Schmidt (2024), or Pibal et al. (2023) support these findings.
2. **Risks in transportation**: Logistics-related risks, particularly transportation risks, show significant sensitivity to both the depth of prefabrication and the scenario. In the Worst Case, transportation risks rise sharply with increasing prefabrication depth, from €60,000 (Level 1) to €213,750 (Level 3). In contrast, these risks are mitigated in the Best Case, where costs are reduced to €12,000 (Level 1) and €190,000 (Level 3), emphasizing the importance of strategic planning and risk management. This strategic lever is supported by the existing studies such as of Borosnyai (2018), Citaku (2023), Lu and Yuan (2013), Rosenberger (2011), or Tam (2007).
3. **Additional effort in joining the components on-site due to complexity:** In the best case, it is expected that no (Level 1) to a very low (one hour per part in Level 3) additional effort, but rather a reduction in costs (see also 'reduced process costs due to prefabrication'). In the worst case, on the other hand, a theoretical value of up to three additional hours (Level 3) per prefabricated part. The complexity of on-site assembly introduces significant cost variations and each level the effort for assembling components increases. This indicates that higher prefabrication levels demand advanced workforce training and efficient assembly processes. However, this risk is significantly minimized by the personnel savings in the reduced process costs.
4. **Leakage Risks for joined components**: Leakage risks, particularly for joined components, are a notable lever in the Worst Case, contributing up to €64,800 in Level 3. However, through improved planning and quality control measures, these risks are reduced to €0 in the Best Case, underscoring the benefits of effective risk mitigation strategies.

Overall, in the Best-Case scenario, the effort required for component assembly represents the highest cost lever, amounting to €240,000 at L3 (prefabrication with exterior plaster). In contrast, in the Worst-Case scenario, transportation risks dominate, with the highest cost value of €213,750 at the same level of prefabrication. The analysis highlights that higher levels of prefabrication increase organizational complexity, particularly under adverse conditions (Worst Case). However, with optimal planning and execution (Best Case), these challenges can be significantly mitigated, making prefabrication a viable strategy for cost optimization and risk reduction.

INCREASED EFFICIENCY

Increased efficiency, measured as cost reductions, is consistently represented by negative values, indicating savings. Higher negative values signify greater efficiency gains. The category of efficiency improvement shows significant sensitivity, especially at higher levels of prefabrication. While savings are less pronounced in the Worst Case, the Best Case demonstrates substantial efficiency gains that significantly enhance economic feasibility.

The key levers influencing efficiency improvements are as follows:

1. **Reduced Process Costs Due to Prefabrication**: Prefabrication significantly reduces process costs, with the Best Case showing the largest savings of €2,880,000 (Level 3). In the Worst Case, these savings are more modest, amounting to €216,000 (Level 3). This highlights the importance of optimizing prefabrication processes to maximize efficiency gains.
2. **Material Savings**: Material efficiency improves with higher levels of prefabrication. However, in the Worst Case, material savings remain relatively low, peaking at €11,743 (Level 3). In contrast, the Best Case demonstrates significant savings of up to €410,080 (Level 3), emphasizing the value of optimized production and material use. The results of the study by Lu and Yuan (2013) support this finding.
3. **Reduced Cleaning Costs on Construction Sites**: Lower cleaning requirements due to prefabrication lead to significant cost savings, especially in the Best Case, where savings increase from €288,000 (Level 1) to €960,000 (Level 3). This demonstrates the environmental impact of prefabrication as shown also in the study by Zhou (2022).
4. **Reduced Cancellation Costs Due to Weather Conditions**: Weather-related cancellations account for the largest efficiency gains, particularly in the Best Case, where savings reach €2,592,000 (Level 3). This lever has the most substantial impact on overall cost reductions, underscoring the importance of promoting weather-independent construction processes.

Material savings are especially relevant at Level 1, where simpler prefabrication allows for more efficient material use. Additionally, the higher quality of prefabrication enables further material savings. For instance, in plastering, we assume that the plaster thickness can be reduced from 12-15mm to 8-10mm, resulting in significant material savings. However, at higher prefabrication levels (Levels 2 and 3), the other levers, such as reduced process costs and weather-related cancellations, become increasingly significant. In the Best Case for Level 3, reduced process costs (€2,880,000) and minimized weather-related cancellations (€2,592,000) represent the largest contributors to cost savings. It should be noted here that, in the best-case scenario, high risks are expected that can be mitigated if they materialise. For example, 30 hours of weather-related cancellation and 18 people required for level 3 are assumed. In addition, a maximum number of projects was calculated here, which, in this case, would all fall within the 'bad weather period'. Still, these findings highlight the potential of advanced prefabrication techniques to drive efficiency and reduce overall project costs. In summary, the data demonstrates that efficiency gains increase substantially with deeper levels of prefabrication, if conditions allow for optimized processes and minimized risks.

DISCUSSION

Figure 4 presents a comprehensive comparative analysis of organizational effort and efficiency gains, derived from the sensitivity analysis of the three scenarios and prefabrication levels. The key findings are summarized below:

1. Organizational effort increases progressively with higher levels of prefabrication, irrespective of the scenario. This trend is consistent across all three prefabrication levels (L1, L2, L3). In practice, organizations must allocate more resources to coordinate these efforts, which could include more specialized staff or increased automation in processes.
2. The Best Case consistently shows lower costs across all prefabrication levels compared to the Worst Case, although the differences between the two scenarios become less pronounced at Level 3 (L3). This suggests that, at higher levels of prefabrication, the impact of varying scenarios diminishes, indicating a stabilization of costs under optimal conditions. In practice, this suggests that investments in process improvement at L3 could yield diminishing returns. Therefore, the focus should shift to enhancing logistics and assembly at this level to capitalize on the high savings potential.
3. Efficiency gains in the Best Case are significant and grow substantially as the level of prefabrication increases. At L3, savings reach up to €6.89 million, highlighting the considerable economic potential of advanced prefabrication techniques. For construction companies, this illustrates that investing in high-level prefabrication can result in dramatic cost reductions.
4. Conversely, the Worst Case shows limited efficiency gains, with lower levels of prefabrication potentially resulting in negative outcomes. The key issue in adverse scenarios is the increased burden of fixed expenses, which becomes more pronounced at lower levels of prefabrication. To mitigate potential negative impacts, companies may need to invest in better forecasting, risk assessments, and adaptive planning tools.

The analysis reveals a clear trend across all scenarios: Higher prefabrication levels (L2 and L3) require more organizational effort but yield the highest efficiency gains. At L3, transport and assembly drive costs. However, strategic logistics, automation, and AI-driven planning streamline operations, offset complexities, and reduce disruptions.

The data from Figure 3 illustrates that organizational effort, when measured against total costs, decreases with higher levels of prefabrication (L1 to L3) across all scenarios (Worst Case, Average, Best Case). In the Worst Case, savings are limited, while in the Average Case they are moderate, and in the Best Case, they are the most pronounced. Particularly at the highest level of prefabrication (L3), the greatest cost advantages are realized. This suggests that higher prefabrication levels lead to significantly lower total costs, especially under optimal conditions.

To mitigate logistics risks and delays, companies can reduce logistical risk through buffer storage, digital tools and flexible supply chains. Standardized modules and digital twins help anticipate disruptions. Here, a key is the positioning of the CODP, which determines the transition from standardized to customized production. Strategic CODP placement balances flexibility and cost efficiency in prefabrication. In conclusion, the findings underscore the potential of prefabrication to reduce both organizational effort and total costs, particularly under favorable conditions. The case study highlights that prefabrication aligns with lean principles by minimizing waste, optimizing material use, and improving workflow efficiency. However, balancing efficiency gains with increasing organizational effort also requires a consideration of the general influences (see Figure 1) such as market conditions, regulatory support, and social attitudes. With a validation of the assumptions and the potential for applying these findings to other construction companies, it is expected that construction processes will continue to shift towards stationary environments, capitalizing on the advantages of prefabrication.

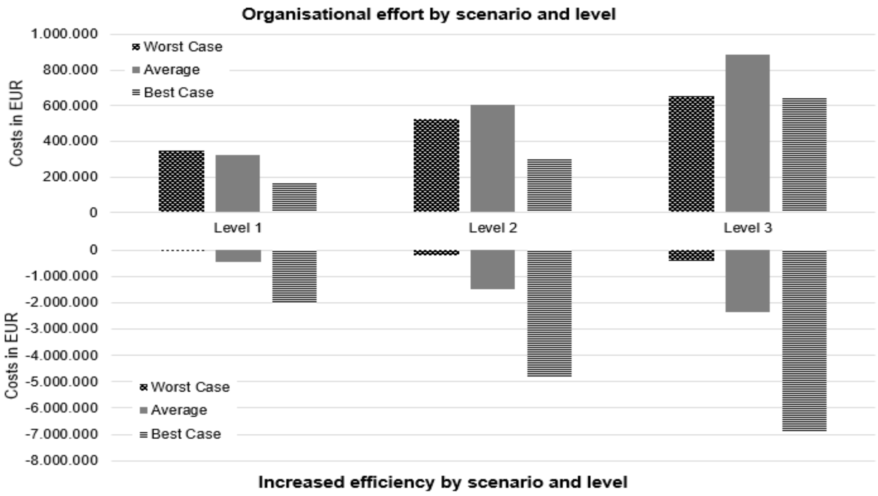

Figure 3: Organizational effort and increased efficiency by scenario and level

CONCLUSION

This case study highlights the potential of industrial prefabrication in the construction industry. The findings indicate that higher levels of prefabrication, lead to reduced costs and increased efficiency. However, these benefits must be weighed against risks, such as logistical complexities and inefficiencies in less favorable conditions.

The key takeaway is that prefabrication, when strategically implemented, can reduce waste, improve safety, and enhance sustainability through more controlled production processes. By aligning prefabrication with lean principles—such as just-in-time delivery and waste minimization—this research contributes to optimizing workflow efficiency and reducing non-value-adding activities in construction. A critical aspect of maximizing these benefits is identifying the optimal integration point, particularly at the CODP, where production shifts from standardized to customized solutions. This study emphasizes the importance of positioning the CODP effectively, ensuring an optimal balance between standardized prefabrication and customized construction needs. The results indicate that an early COPD and high level of prefabrication leads to cost reductions and efficiency gains primarily when supported by strong logistics and strategic planning, as evidenced by the comparative analysis of prefabrication levels (L1, L2, L3). While this case study provides valuable insights, its findings are limited to the specific industry partner's context. Broader applicability requires further validation across diverse projects and market conditions.

To support wider adoption, policymakers should encourage prefabrication through tax incentives, subsidies and regulations that support standardization and material reuse. Integrating circular economy principles, —such as design for disassembly, material circularity, and resource-efficient life-cycle strategies—enhances sustainability by extending building lifespans and reducing waste. Future research should compare sectors to refine best practices for integrating prefabrication into lean construction, improving efficiency and minimizing waste. As adoption of these techniques grows, prefabrication can help mitigate risks such as weather delays and material shortages, contributing to a more streamlined, cost-effective, and resilient construction sector.

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