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Using Lean Principles to Optimize the Delivery Process of Façade Engineering

Marie Belle Georges[1], Issam Srour[2], and Hicham Abou Ibrahim[3]

Abstract

Question: How can Lean Construction principles, and Value Stream Mapping (VSM) in particular, be applied to visualize and improve the façade engineering delivery process?

Purpose: The purpose of this study is to develop and apply current-state and future-state Value Stream Maps to the façade engineering delivery process to identify sources of workflow inefficiency and propose Lean-based improvements.

Research Method: The study applies a Design Science Research approach to a representative façade engineering case, combining semi-structured interviews with 15 international façade experts and a systematic literature review to define process phases and consultant–contractor interfaces, and develop current and future-state VSMs.

Findings: The current-state VSM reveals significant inefficiencies related to fragmented communication, late contractor involvement, design rework, approval delays, and information handoff discontinuities. The future-state VSM demonstrates that early contractor involvement and digital collaboration platforms can substantially reduce workflow fragmentation and non-value-added activities, with expert informed estimates indicating up to a 60% reduction in non-value-added time.

Limitations: The VSM was developed using a generic façade case and expert judgment rather than project-specific quantitative data; therefore, the results indicate potential improvements requiring empirical validation.

Implications: The study demonstrates that Lean principles and VSM can be effectively adapted to engineering intensive, iterative delivery processes, extending their application beyond traditional linear construction workflows.

Value for practitioners: The proposed VSM framework enables façade stakeholders to visualize workflows, diagnose delays and rework, and improve coordination, predictability, and delivery performance.

Keywords: Lean Construction, Value Stream Mapping, façade engineering, workflow

[1] PhD Candidate, Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon, msg20@mail.aub.edu

[2] Professor, Department of Civil and Environmental Engineering, American University of Beirut, Beirut, Lebanon, is04@aub.edu.lb

[3] Assistant Professor, Department of Industrial Engineering and Management, American University of Beirut, Beirut, Lebanon, ha306@aub.edu.lb

variability, early contractor involvement, process optimization.

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Introduction

Building facades represent the complete integrated system that separates indoor spaces from outdoor elements constituting a fundamental structural component (Luo et al., 2019; Oral et al., 2004; Parfitt, 2007). Within the construction industry, facade engineering is a specialized field that focusses on building envelope design, construction, and maintenance. Multidisciplinary stakeholders work through collaborative processes to address complex geometries and strict performance constraints while managing diverse materials and systems as identified by (Gilani et al., 2022) and (Voss et al., 2013). The façade delivery process faces multiple implementation challenges such as delays, inefficiencies and rework caused by design changes together with material issues and poorly planned or disrupted construction sequencing. Coordination amongst various stakeholders as well as the lack of specialized knowledge in the field and logistical issues with planning and coordination for facade delivery processes negatively affect these challenges. The impacts on project time, cost and quality caused by these challenges compel the need to develop optimized workflows, which improve performance results.

The challenges associated with facade engineering are comparable to the widespread inefficiencies in the construction industry, where lean concepts have been effectively implemented to improve project results and streamline processes (Karmaoui et al., 2023; Ko & Chung, 2014; Ko & Kuo, 2019; Nowotarski et al., 2016). By using tools like Value Stream Mapping (VSM) to identify inefficiencies and reduce delays, the lean construction management approach aims to increase client value and decrease waste (Espinoza et al., 2021; Gunduz & Naser, 2019; Itani et al., 2022; Pasqualini & Zawislak, 2005). Research shows that lean principles application in façade engineering is limited in comparison with its widespread application in the construction industry (Chung & Mutis, 2016; Friblick et al., 2009). Given the technical complexities and project-specific requirements of façade projects, it becomes essential to leverage lean approaches since they offer major possibilities for solving existing process challenges and optimize delivery processes (Friblick et al., 2009).

Research on facade engineering has been dominated by technical performance areas such as structural behavior, thermal performance, durability, and material optimization. These studies are very crucial, but they provide very little information on the delivery of facade systems at different stages of the project or how workflow coordination, information sharing, and consultant-contractor interfaces affect delivery performance. As a result, limited attention has been given to the delivery process itself, including workflow coordination, information exchange, and consultant-contractor interfaces (Htet et al., 2023).

This research employs data from expert interviews together with existing literature findings to apply Value Stream Mapping (VSM) to the façade engineering delivery process. The study aims to answer two main questions: (1) what are the process inefficiencies embedded in the current façade delivery process (visualized using current state VSM)? and (2) where can potential enhancements be made (visualized on the future state VSM)?.

Literature Review

The literature review investigates essential areas related to this research. The initial part details façade engineering process complexity and its iterative nature before introducing an overview of lean methodologies in the construction industry. The following section discusses challenges faced during façade engineering delivery process and finally examines where Lean Principles particularly VSM fall short when applied to façade engineering.

Façade Engineering Delivery Characteristics

Building on the introductory overview, this section examines façade engineering from a delivery-process perspective, focusing on workflow characteristics relevant to Lean analysis. The iterative nature of façade engineering arises from its inherent complexity (Kassem & Mitchell, 2015), multidisciplinary requirements (Bianchi et al., 2024), and the involvement of stakeholders with differing priorities and areas of expertise (Raphael, 2014). Bianchi et al. (2024) note that this complexity necessitates structured and comprehensive planning to reconcile competing performance requirements. Similarly, Raphael (2014) explains that managing these competing priorities leads to multiple cycles of design optimization extending from early design stages through to delivery.

Building facades require specialized knowledge which combines architectural design together with engineering principles and material science alongside construction technology for creating functional building envelopes according to (Htet et al., 2023). The complex nature of façade engineering creates a delivery process featuring multiple design modifications, interactions with multiple stakeholders and adjustments to meet aesthetic and performance requirements along with regulatory needs which all require successful stakeholder collaboration (Zhilyaev et al., 2022). These iterative processes, driven by ongoing design revisions and input from stakeholders, frequently result in delays and rework, compromising on cost, time, and sometimes quality requirements.

This study focuses on three main challenges encountered during the façade engineering delivery process:

- Iterative Workflows: Façade design is an iterative process. Project requirements that evolve throughout the design phase together with opposing stakeholder feedback cause regular design alterations (Bianchi et al., 2024; Rammig et al., 2023).
- Role Ambiguity: Miscommunications and delays are caused by the overlapping duties between façade consultants and contractors which create role ambiguity (Bianchi et al., 2024; Htet et al., 2023; Rammig et al., 2023).
- Complexity of Integration: Façade implementations must equally integrate several essential parameters from architectural intent to structural requirements alongside environmental performance and construction(Bianchi et al., 2024; Rammig et al., 2023; Zhilyaev et al., 2022).

These challenges collectively create workflow variability, an aspect central to Lean Design and Lean Construction research.

Lean Methodologies in Construction

The VSM developed in this study maps the entire façade delivery process, from early design through construction and post-construction phases. In contrast, the literature review focuses primarily on design and engineering workflows, where workflow variability and coordination challenges are most extensively theorized within Lean Construction research. These first stages cause the majority of variation, rework and coordination issues that subsequently impact fabrication and installation. In the design setting, lean research has historically focused on enhancing workflow reliability, therefore it is the most pertinent starting point to analyzing facade delivery inefficiencies. To structure the review around design and engineering is thus compatible with the Lean Construction theory, whereas the entire process VSM enables the research to track the way in which problems spread upstream across the entire facade delivery process.

Overview of Lean Construction Theory and Tools

The Lean Construction is based on the concepts developed by the Toyota Production System (Liker & Morgan, 2006), which focuses on emphasizing waste reduction, value creation, and reliable workflow performance. Contemporary research confirms the improvements in non-value-added operations (Elmalky et al., 2024; Jejurkar & Kesarkar, 2023; Uttamrrao et al., 2023), based on the Lean theory of flow and waste reduction (Ballard & Howell, 2011; Koskela, 1992). Equally, recent developments on value improvement (Ionel, 2024) are consistent with the production-system perspective that value is created through improved flow and reduced variability (Koskela, 1992; Sacks et al., 2010). The literature on workflow optimization (Gupta et al., 2025) also supports the ideas initially presented in Lean Construction literature about the relevance of stable and predictable production systems (Ballard & Howell, 2002; Tommelein, 1998). More general arguments on the variability of the construction and system disruptions (Nowotarski et al., 2016) also indicate the traditional issues in Lean Studies regarding planning unreliability and fragmented information flow (Alsehaimi et al., 2009).

The Lean Construction theory is based on the conceptualization of construction as a production system introduced by Koskela (1992) and focuses on enhancing the reliability of workflow, decreasing the variability, and increasing coordination among project teams. Foundational studies by Ballard and Howell (2002) and Tommelein (1998) reveal that consistent planning, elimination of constraints, and workflow variability management are some of the key processes at stabilizing production flow. Empirical research findings constantly indicate that fragmentation and inconsistent information flows interfere with workflow performance in a construction environment (Ballard & Howell, 2002; Sacks et al., 2010). Recent studies highlight the relevance of Lean as projects become more complex and unpredictable, and the necessity of integrated planning systems and solid flow control is strengthened (Daniel et al., 2017; Peñaloza et al., 2016). Contemporary studies also reveal the impact of variability and planning instability on reducing reliability, which reinforces the argument of Lean-grounded management styles in complex settings (Daniel et al., 2015; Sarhan et al., 2017). The contributions of constraint elimination and task preparedness to enhanced predictability are also confirmed by lookahead planning studies (Hamzeh et al., 2012; Hamzeh et al., 2015).

Value Steam Mapping (VSM) is one of the key tools of Lean to visualize working processes and determine bottlenecks (Gonzalez et al., 2024; Tyagi et al., 2015). VSM allows the systematic study of the current state processes and construction of more effective ones as future state processes (Gunduz & Naser, 2019; Naser et al., 2023; Pasqualini & Zawislak, 2005). Its versatility is demonstrated by its use in a variety of areas, such as window production (Itani et al., 2022), diagnostics of basement construction (Espinoza et al., 2021), and Digital Twin–enabled brick production (Karmaoui et al., 2023). These applications show that VSM is flexible and can be used to model complex engineering processes when properly put into context with Lean principles.

Lean in Design and Engineering Workflows

Design and engineering workflows frequently experience instability due to fragmented information flows, incomplete inputs, and interdependent task sequences. According to foundational Lean Design research, the main sources of design-phase waste and variability are the lack of information, ambiguous task interfaces, and unreliable handoffs (Tzortzopoulos & Formoso, 1999). More recent Lean Design studies reinforce these findings by showing how insufficient definition of information requirements and design maturity directly affects workflow reliability and task sequencing (Abou-Ibrahim & Hamzeh, 2016). Similar problems are verified in recent work, which demonstrates that evolving requirements and documentation inconsistencies are contributing factors to delay and rework within design teams (Daniel et al., 2015; Morales-Caballero et al., 2025; Peñaloza et al., 2016b; Rodriguez-Trejo et al., 2017). Studies of engineering design interdependency also show the development of iterative loops by tightly coupled tasks when upstream decisions change or information is received late (Ko & Chung, 2014).

Lean Design Management addresses challenges associated with enhancing the reliability of the workflow, readiness of tasks, and the enhancement of coordination. Lookahead planning and “tasks made ready” practices have shown measurable improvements in predictability (Hamzeh et al., 2012; Hamzeh et al., 2015). Complementary modeling-based research further demonstrates how stakeholder interactions and decision dependencies influence design workflow dynamics, highlighting the systemic nature of coordination challenges in design environments (Abou-Ibrahim & Hamzeh, 2022). Misalignment of coordination, role ambiguity, and communication gaps are still among the key contributors to instability in workflow (Burke & Parrish, 2018; Demir & Theis, 2016). The integration between Lean and BIM has also optimized information flow between design teams (Herrera et al., 2021) while Lean-oriented control of design batch size has been proposed as a mechanism to stabilize workflow and reduce iteration-driven delays (Lappalainen et al., 2025) alongside empirical evidence that managing batch size and variability enhances design throughput (Lappalainen et al., 2021). Patterns of rework and variability are also reported in engineering-intensive design settings (Daniel et al., 2015; Peñaloza et al., 2016b).

Challenges such as fragmented information, unstable handoffs, dependency-driven rework, and high iteration, closely mirror those observed in façade engineering. However, the field of Lean Design research has been predominantly applied to architectural and structural processes, covering little of the engineering-intensive field such as facade engineering (Tzortzopoulos et al., 2020). This gap underscores the need to extend Lean-based workflow analysis to façade-specific processes.

Value Stream Mapping in Construction and Opportunities for Adaptation

Value Stream Mapping (VSM) has been known to effectively map processes, visualize the performance of workflows, and identify waste and potential areas of improvement (Gonzalez et al., 2024; Tyagi et al., 2015). VSM helps to identify inefficiencies in a systematical way and formulate specific improvement strategies by explaining the flow of information, points of decisions, and interdependence of processes (Gunduz & Naser, 2019; Naser et al., 2023). The tool has proven to be robust and flexible as evidenced by the successful application in construction.

Even though VSM was developed in the context of linear manufacturing, its systematic methodology offers a solid basis to the modeling of more intricate engineering processes. Even though VSM has been used in primarily linear construction processes, current research demonstrates that it can be extended to iterative and multidisciplinary design when adapted to information flows and decision-making cycles. The flexibility is evidenced by emerging applications in modular and engineer-to-order design, and the possibilities of VSM in enhancing the complex design workflow are highlighted (Peñaloza et al., 2016b).

Research in process-modelling supports the relevance of workflow visualization in an engineering setting since rework cycles, dependency on information and repetitive decisions are supported by the approach that involves structured mapping approaches (Martinez Lagunas & Nik-Bakht, 2024). All these insights imply that VSM has unexploited potential to serve the purposes of facade engineering as long as it is adjusted to capture the specifics of the facade delivery processes.

Research Gap

Despite the successful application of lean tools in various construction domains (Ko & Kuo, 2019; Nguyen et al., 2020; Ramani & KSD, 2019), their use within façade engineering remains limited. Façade projects exhibit distinct characteristics, including bespoke design specifications, iterative performance-based analyses, and overlapping consultant–contractor interactions, which are not fully addressed by conventional lean approaches (Htet et al., 2023). As a result, further investigation is required to understand how Lean Construction principles and Value Stream Mapping (VSM) in particular can be translated to address the workflow-specific challenges inherent in façade engineering.

Existing VSM applications in construction predominantly target linear or standardized production processes. In contrast, façade engineering workflows are highly customized, iterative, multidisciplinary, and governed by performance-based specifications. These characteristics do not render VSM unsuitable; rather, they reveal its untapped potential within façade delivery and underscore the need for contextualization to accurately represent façade-specific workflow behavior.

This gap highlights the need for a façade-specific adaptation of VSM capable of visualizing the iterative and multidisciplinary nature of façade design and delivery, while identifying opportunities for workflow optimization in this specialized engineering context. By addressing this gap, the present study contributes to Lean Construction research and supports the practical improvement of façade delivery processes.

Research Methodology

This study adopts a Design Science Research (DSR) methodology to develop the current and future Value Stream Mapping (VSM) of the façade engineering delivery process. As an iterative method, DSR combines innovation development with practical solution evaluation toward academic knowledge growth. DSR differs from classic research methods because it centers its activities on developing and refining solutions consisting of frameworks, models or processes which address practical real-world problems (Pastor et al., 2024; Zare et al., 2024). This paper introduces the initial version of VSM, which will undergo future iterations after receiving feedback and updates from experts in façade engineering.

The research foundation started with a systematic literature review that identified major challenges and inefficiencies in façade engineering and overall construction industry. Several references particularly (Gunduz & Naser, 2019) and (Ko & Kuo, 2019)demonstrated how Lean tools such as VSM operate effectively in construction projects. Concurrently, research specific to façade engineering emphasized repetitive challenges in the field such as iterative workflows, role ambiguity, and coordination challenges (Bianchi et al., 2024; Htet et al., 2023).

To ground the VSM in practical relevance, semi-structured interviews were conducted with 15 global façade experts, findings from expert interviews will be thoroughly reported in a future research paper. The interviews conducted specific research on process inefficiencies at consultant-contractor interfaces while collecting stakeholder information about project phase collaboration. A thematic analysis following (Braun & Clarke, 2006) method allowed researchers to identify dominant patterns within the collected qualitative data through transcription. An important finding from the data collected was that most facade building projects, around 90%, operate with performance-based specifications documentation that determines how project responsibilities and roles are established. It is worth mentioning that the façade engineering performance-based specifications detail the functional and performance requirements including structural integrity, thermal efficiency, acoustic and fire requirements and aesthetics. However, it does not specify nor prescribe a specific façade system allowing contractors to achieve compliance through their chosen approaches. The obtained insights proved necessary for both stakeholder interaction mapping and phase boundary definition and VSM improvement regarding existing inefficiencies.

Through a generic case study that the researchers are familiar with, which consists of a relatively small size façade project that encompass a low to mid-rise building of approximately 6 to 9 stories with facade area around 1,000–2,000 m^2. The building reflects a standard medium-scale commercial facility or institutional building using unitized curtain wall systems and aluminum cladding panels on its four elevations. A current state VSM was developed to map and analyze the current façade delivery process. Data gathered through semi-structured interviews with global façade experts and a review of project documentation. The delivery process mapping covered all phases from concept design through to post-construction where it captured all the major phases. The current state VSM provided a visual representation of process flow distribution that led to detecting non-valuable tasks for potential improvements. Inefficiencies were identified such as delays, bottlenecks, and non-value-added activities. A proposed future state VSM was then applied to enable the development of an optimized process design.

Preliminary Results

By analyzing the current state VSM (Figure 1) and proposing a future state VSM (Figure 2) of the façade engineering delivery process, inefficiencies were identified, and opportunities for improvement were mapped. The scope of this paper focuses on the interface between façade consultant and façade contractor within the façade engineering delivery process. Production and installation phases are part of another ongoing study.

Current State VSM

By applying the current state VSM (Figure 1) to a generic façade project case study that the researchers are familiar with, the following key inefficiencies were revealed across the delivery process:

- Fragmented Communication: A lack of direct and synchronized communication and coordination between consultant and contractor was identified, leading to process delays and rework challenges.
- Frequent Wait Times and Bottlenecks: Delays caused by waiting for inputs and approvals from multidisciplinary stakeholders were observed across multiple phases, contributing significantly to inefficiencies such as the wait time it takes to review shop drawings, structural and thermal calculations by the consultant causing delays to up to 4 weeks in the project presented in this study, which is significant in a small size project.
- Rework and Design Iterations: Rework and design iterations during the concept and detailed design phases were attributed to the varying maturity levels of other design stakeholders' packages as illustrated in Figure 1. Major rework issues were also identified between the detailed design phase/tender phase and the subsequent design of shop drawings during the construction phase due to the nature of the performance-based design documentation where the design intent along with outline of the functional and performance requirements of the system are provided in the tender package giving the flexibility for the contractor to select a specific compliant system design in the construction phase.
- Approval Delays and Non-Value-Added Time: Prolonged approval processes contributed significantly to non-value-added time. In the current VSM for the presented project, the non-value-added time was calculated to be 14 weeks out of a total lead time of 30 weeks, which is quite significant for a small sized façade project; highlighting opportunities for reduction.

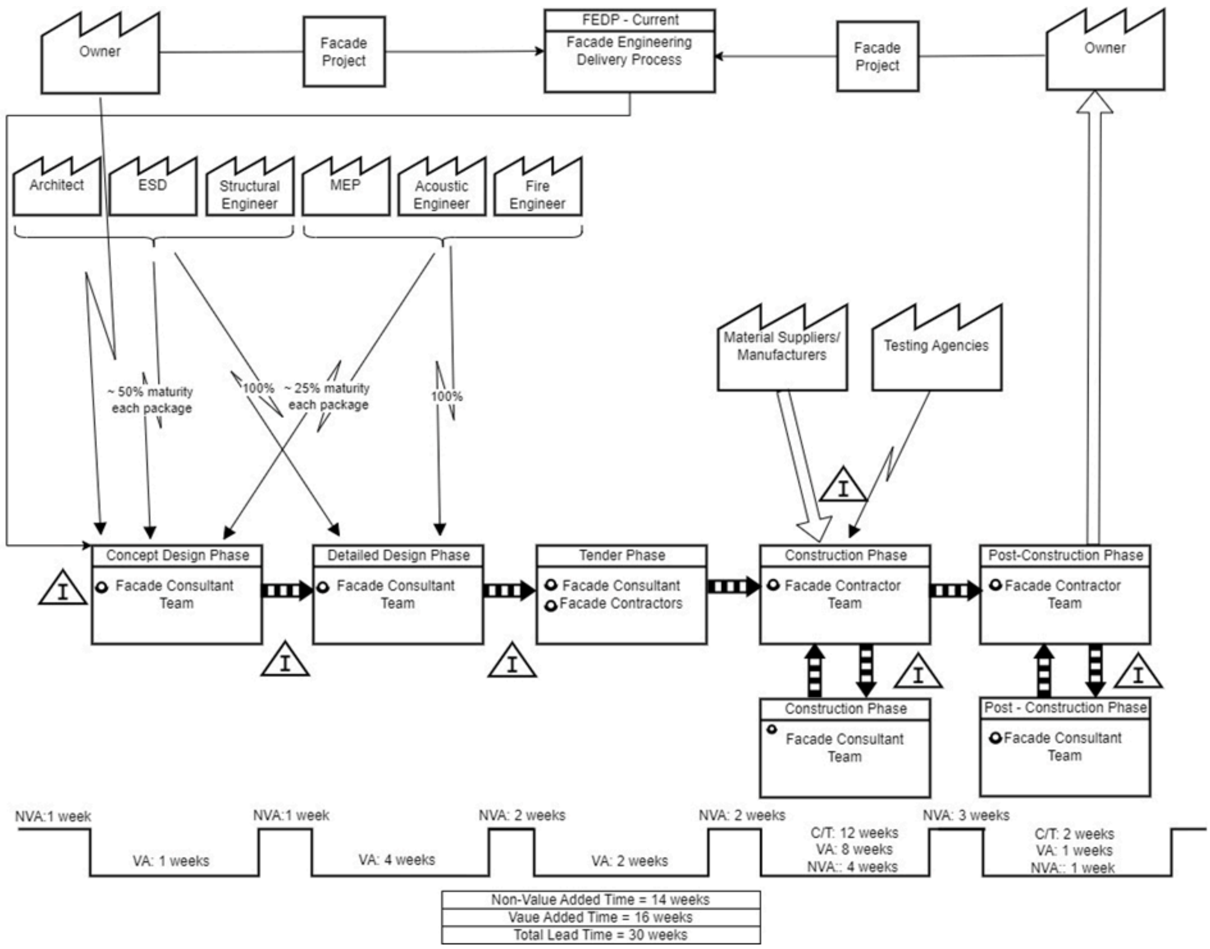
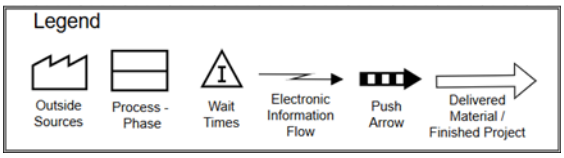


Figure 1. Current VSM Facade Engineering Delivery Process



Future State VSM Proposals

To address the inefficiencies identified in the current VSM, this study proposes a future state VSM (Figure 2) to streamline the façade engineering delivery process. The future state VSM suggests the following improvements to the existing process.

- Early Contractor Involvement (ECI) includes inviting up to three facade contractors whose involvement is necessary at the detailed design phase for advice on feasibility guidance and constructability to decrease rework and enhance process efficiency. The involvement of contractors at an early stage enables early evaluation of material and façade system selections while helping in identifying potential risks and buildability issues that enables better and more precise contractor bidding as the design approaches completion. The design collaboration results in faster shop drawings preparation combined with reduced delays because the contractor can simultaneously review design details and initiate preparation of shop drawings before design completion. Justifying the tender phase, this approach aids in developing accurate bidding which limits unforeseen issues and provides better transitions between design and construction stages.

- Digitalized Collaboration Platforms such as BIM and IOT are proposed to enable the integration of contractors early in the process and to enable the generation of multiple design sets in parallel. These platforms are expected to enhance real-time communication between stakeholders at the early phases of the design and communication and collaboration between consultant and contractor at the construction phase where dependency of diverse inputs and feedback is present, ensuring better management and reducing the need for rework.
- Approval Delays and Non-Value-Added Time: Lean solutions in this context which included ECI, streamlined approval processes and parallel processing reduced façade project non-value-added time to 5.5 weeks. The implementation of this method reduced the total lead time to become 20.5 weeks through a significant time reduction which is ideal for a small sized façade project.

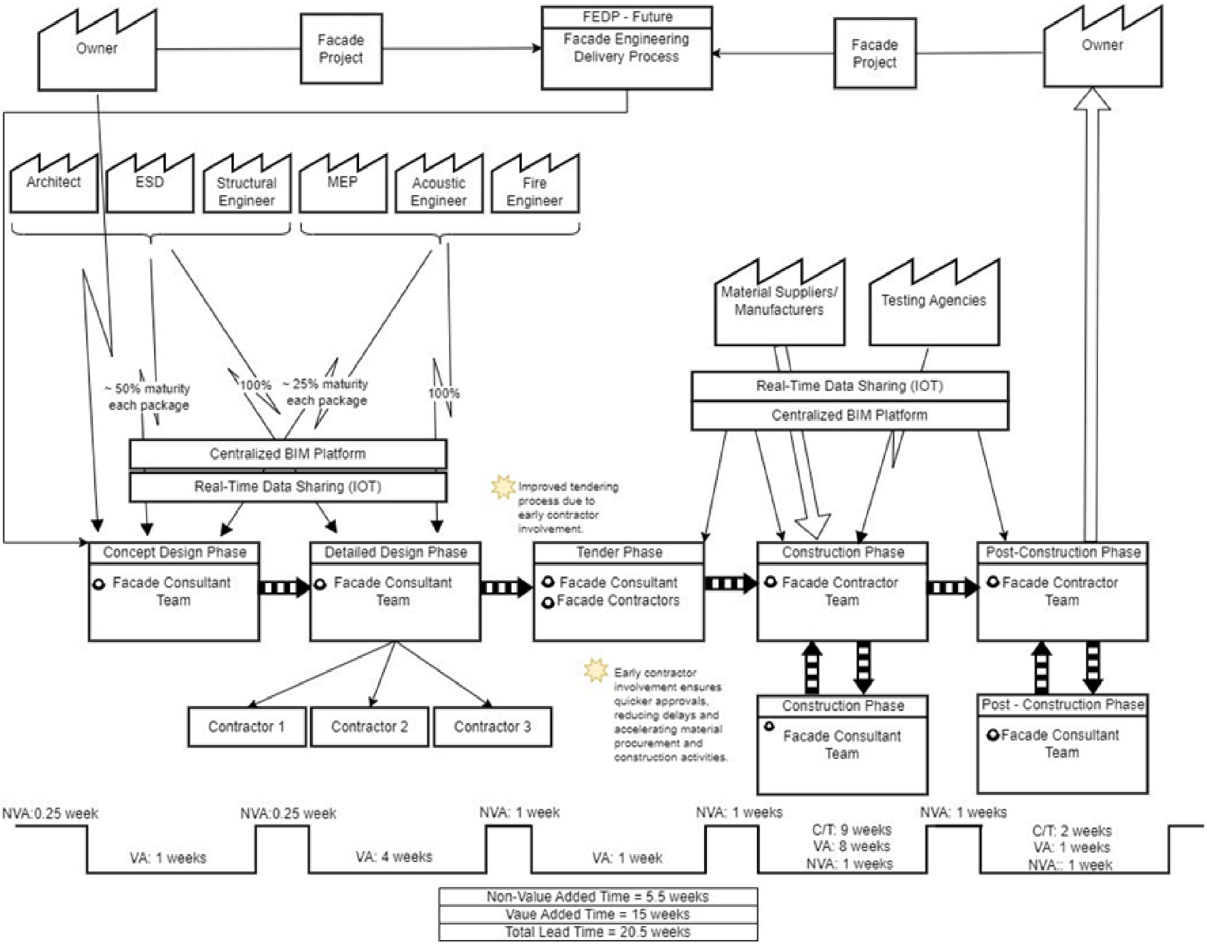


Figure 2. Future VSM Proposal Facade Engineering Delivery Process

Discussion

As illustrated in the Preliminary Results Section, the current state VSM highlights persistent inefficiencies in the delivery process. The façade engineering delivery process is hindered by fragmented communication, frequent wait times and bottlenecks, rework and design iterations and approval delays. These results are in line with the challenges that have been found in previous Lean Construction research, suggesting that the discontinuity of information flows, and delayed decision-making reduces the trustworthiness of workflow processes in complex project settings (Ballard & Howell, 2002; E. Daniel et al., 2017; Sacks et al., 2010; Tzortzopoulos & Formoso, 1999). This alignment with prior research confirms that the façade delivery process exhibits workflow characteristics commonly addressed by Lean Construction theory. These inefficiencies are magnified in facade engineering by the performance-based and highly iterative delivery process, which results in delays in schedule and overruns in cost, based on expert interviews and literature research findings.

The current-state Value Stream Map functions as a diagnostic means to understand the distinctive features of the façade engineering delivery process. The traditional delivery process depicts the façade contractor's involvement at the construction phase, whereas façade consultants typically issue tender design drawings along with performance-based façade technical specifications. The tender package often lacks system-specific details required for fabrication until a façade contractor is engaged. As a result, when façade contractors are finally involved at the construction phase, they must redevelop the design through shop drawings that reflect the actual systems to be installed. The transition between consultant-contractor causes delays and time losses along with conflicting requirements which necessitate multiple redesign efforts leading to decreased effectiveness. In addition, real-time collaboration and coordination become challenging due to lack of digital collaboration platforms in place which leads to higher inefficiencies and duplicated work. Hence, mapping the current state VSM helps visualize and identify inefficiencies as well as making the resulting wait times and information dependencies measurable. This is important due to the fact that the Lean tools focus on the identification and removal of non-value-added processes. The analysis shows how VSM can be used not only on linear processes but also on workflows that are knowledge-intensive and engineering-intensive as an extension of its applicability well beyond the usual production environments by making the loops of iterations and information disconnections visible.

The future-state VSM proposes two enablers to optimize the delivery process comprising early contractor involvement (ECI) and digital collaboration platforms. Early involvement of façade contractors in the design development phase improves project constructability while performing less redesigned work. Besides, digital platform enhances real-time collaboration and communication channels among stakeholders. Nonetheless, the current widespread adoption of both enablers is still limited in the industry nowadays perhaps due to cultural resistance, digital literacy gaps, and contractual difficulties. The present situation persists in many projects across the globe due to these challenges. These findings reflect challenges previously identified in Lean implementation research, where organizational and contractual barriers frequently hinder process innovation. Nevertheless, mapping the proposed future state VSM along with expert feedback and proposed improvements positions as a practical and valuable steppingstone towards an optimized façade delivery process.

These enhancements were not selected randomly; they were the results of the Lean analysis. The future-state VSM shows how the implementation of the Lean Principles, i.e., visualization, identification of waste, and the improvement in flow can transform the facade delivery process into a more predictable and integrated process. This study contributes to Lean Design and Lean Construction research by demonstrating that Value Stream Mapping can reveal sources of process variability and waste in highly iterative, engineering-intensive contexts where Lean tools have been applied less frequently. Moreover, the approach adopted here is generalizable and can be adapted to other engineering-intensive trades such as MEP, structural steel, and modular systems, where multidisciplinary inputs and iterative decision cycles similarly affect workflow reliability. In general, the analysis of the present and future VSMs demonstrates the usefulness of Lean tools in an engineering-intensive field; showing that visualization supports systematic diagnosis and enables targeted process redesign rather than reactive problem-solving.

Conclusion

In conclusion, this research develops a current state and future state Value Stream Mapping (VSM) to enhance façade engineering delivery process using expert interviews, literature review and an informal use of Design Science Research (DSR) methodology applied to a representative facade case. The current-state VSM indicates the lack of efficiency in the form of approval bottlenecks, redesign loops, and coordination delays. The advantage of VSM approach is that it simplifies an otherwise complex and iterative process into a visual representation that reveals points of waste and variability in the workflow. This diagnostic clarity provides the foundation for structured Lean-based improvements.

The future-state VSM shows that fragmentation in the workflow can be reduced with the involvement of the contractor at an early stage (ECI) and the implementation of digital collaboration platforms that would decrease non-value-added time. This adds to the Lean Construction theory by showing how VSM can be successfully implemented in engineering-based design-focused settings and is not restricted to more linear construction processes.

The study demonstrates the applicability and usefulness of Lean methods in the field of facade engineering, by demonstrating that Lean principles and VSM can be directly used to inform the design of a better process in a field where Lean is rarely used. The paper offers actionable guidelines to implement lean principles in the facade delivery process. Early contractor involvement and enhanced communication channels through digital platforms lead to enhanced coordination, thereby reduced iterations and improved timelines.

One of the limitations of the study is that the VSM was formulated with a generic facade case and expert knowledge instead of quantitative data associated with the project. In this regard, the extent of improvement must be confirmed empirically. Future work will involve a non-theoretical project-based data for the validation of the VSM along with simulation modelling to test the framework, exploring scenarios that evaluate different configurations of VSM in improving workflow efficiency and the integration with BIM or Digital Twin systems to create dynamic, data-rich representations of facade delivery workflows. The methodological approach introduced in this paper also has the potential to be adapted to other engineering-intensive fields with similar workflow issues.

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Disclaimer

During the preparation of this work, the author(s) used ChatGPT to improve the language and readability of some paragraphs in the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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