



Using Lean Principles to Optimize the Delivery Process of Façade Engineering

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ABSTRACT: The façade engineering delivery process is intrinsically complicated, with multi-phase interactions among various stakeholders and iterative procedures. Process optimization becomes hindered by the key challenges of rework, delays and bottlenecks that arise within the delivery framework. Value Stream Mapping (VSM) originating from lean manufacturing has demonstrated use across construction projects but shows minimal implementation in facade engineering applications. This study establishes current and future state VSM frameworks for façade engineering to improve delivery process quality. The study builds its findings on 15 global façade expert insights through a systematic literature review to identify vital phase boundaries and define consultant and contractor responsibilities. Through Design Science Research, the VSM integrates results from best practice research with semi-structured interview data that targets problems in consultant-contractor interaction processes. The implementation of VSM helps facade engineering projects decrease delay times while increasing coordination and streamlining workflow operations. The preliminary research findings demonstrate that VSM provides effective tools to cut waste and optimize resource transfers as well as communication among team members, achieving up to 60% reduction in non-value-added time. The results obtained will enable real-world project applications. This study serves as an example for streamlining complex delivery systems across various construction sectors and supports the overall implementation of lean practices in construction management.

1. 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 and Chung 2014; Ko and 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 and Naser 2019; Itani et al. 2022; Pasqualini and Zawislak 2005). Research shows that lean principles application in facade engineering is limited in comparison with its widespread application in the construction industry (Chung and Mutis 2016; Friblick et al. 2009). Given the technical complexities and project-specific requirements of facade 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).

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

2. LITERATURE REVIEW

The literature review investigates essential areas related to this research. The initial part details facade 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 facade engineering delivery process and finally examines where lean principles fall short when applied to facade engineering.

2.1 Façade Engineering

The iterative nature of facade engineering originates from its inherent complexity (Kassem and Mitchell 2015), multidisciplinary needs (Bianchi et al. 2024) and stakeholder involvement with different priorities and expert knowledge (Raphael 2014). Bianchi et al. (2024) indicate that the complexity requires structured comprehensive planning which merges competing performance requirements. According to Raphael (2014), the process of managing competing priorities entails multiple iterations of design optimizations which extend from early design work to the delivery phase.

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 facade 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 facade 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 facade 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 feasibility (Bianchi et al. 2024; Rammig et al. 2023; Zhilyaev et al. 2022).

2.2 Lean Methodologies in Construction

Lean Principles, delivered by the Toyota Production System (Liker and Morgan 2006), focus on waste reduction (Elmalky et al. 2024; Jejurkar and Kesarkar 2023; Uttamrao et al. 2023) and value enhancement (lonel 2024) as well as workflow optimization (Gupta et al. 2025). These principles have steadily gained value in construction management because they enable effective management of complicated intensive resource processes (Nowotarski et al. 2016). Value Stream Mapping (VSM) serves as an essential lean tool to visualize workflows and pinpoint bottlenecks (Gonzalez et al. 2024; Tyagi et al. 2015). The application of VSM enhances project delivery through its ability to analyze current process structures before designing optimized efficient future states (Gunduz and Naser 2019; Naser et al. 2023; Pasqualini and Zawislak 2005), ultimately leading to enhanced process outcomes.

Research indicates that Value Stream Mapping (VSM) proves successful for the construction production process. Abdel-Jaber et al. (2022) linked VSM functionality to simulation technology within their hybrid lean system for window manufacturing production to improve efficiency. Espinoza et al (2018) utilized Value Stream Mapping to analyze basement construction failures through bottlenecks identification. Karmaoui et al (2023) developed a system that merged Value Stream Mapping with Digital Twins in brick production and explained how lean tools and Industry 4.0 technology improve transparency and productivity.

Despite the success of lean tools in other construction domains (Ko and Kuo 2019; Nguyen et al. 2020; Ramani and KSD 2019), their application in façade engineering remains largely unexplored. To the best of our knowledge, no study has explicitly examined how lean principles can be adapted to address the unique challenges of façade engineering.

The application of lean to façade engineering is underexplored by researchers although these tools successfully operate in multiple construction areas (Ko and Kuo 2019; Nguyen et al. 2020; Ramani and KSD 2019). To the best of our knowledge, no study explored how lean principles and tools such as Value Stream mapping can be applied to tackle specific unique challenges found in façade engineering. There are unique challenges of the façade field such as bespoke design and overlapping interaction between consultant-contractor which standard lean approach do not fully address (Htet et al. 2023). Research must explore adaptations of lean principles that specifically address façade engineering challenges while developing solutions to solve these issues.

The literature reveals a rising interest in effective lean applications in the construction industry but highlights a lack of focus in the façade engineering field. This research aims to fill this gap by applying Value Stream Mapping to the façade engineering delivery process. By doing so, it contributes to both the academic understanding and practical optimization of this significant process. Existing VSM in construction examine linear processes and standardized activities that follow defined sequences. The iterative nature of the delivery process of façade engineering consists of high customization requirements along with performance-based specifications and specialist subcontractor reliance. Construction VSM frameworks do not reflect the unique behavioral patterns which exist during facade project execution. Developing an approach dedicated to façade-specific VSM implementation becomes essential for creating effective mapping of the delivery process together with proper analysis and improvement in this specialized area.

3. 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 and Naser 2019) and (Ko and 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 and 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 m². The building reflects a standard medium-scale commercial facility or institutional building using unitized curtain wall systems and aluminium 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.

4. 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 an ongoing study.

4.1 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.

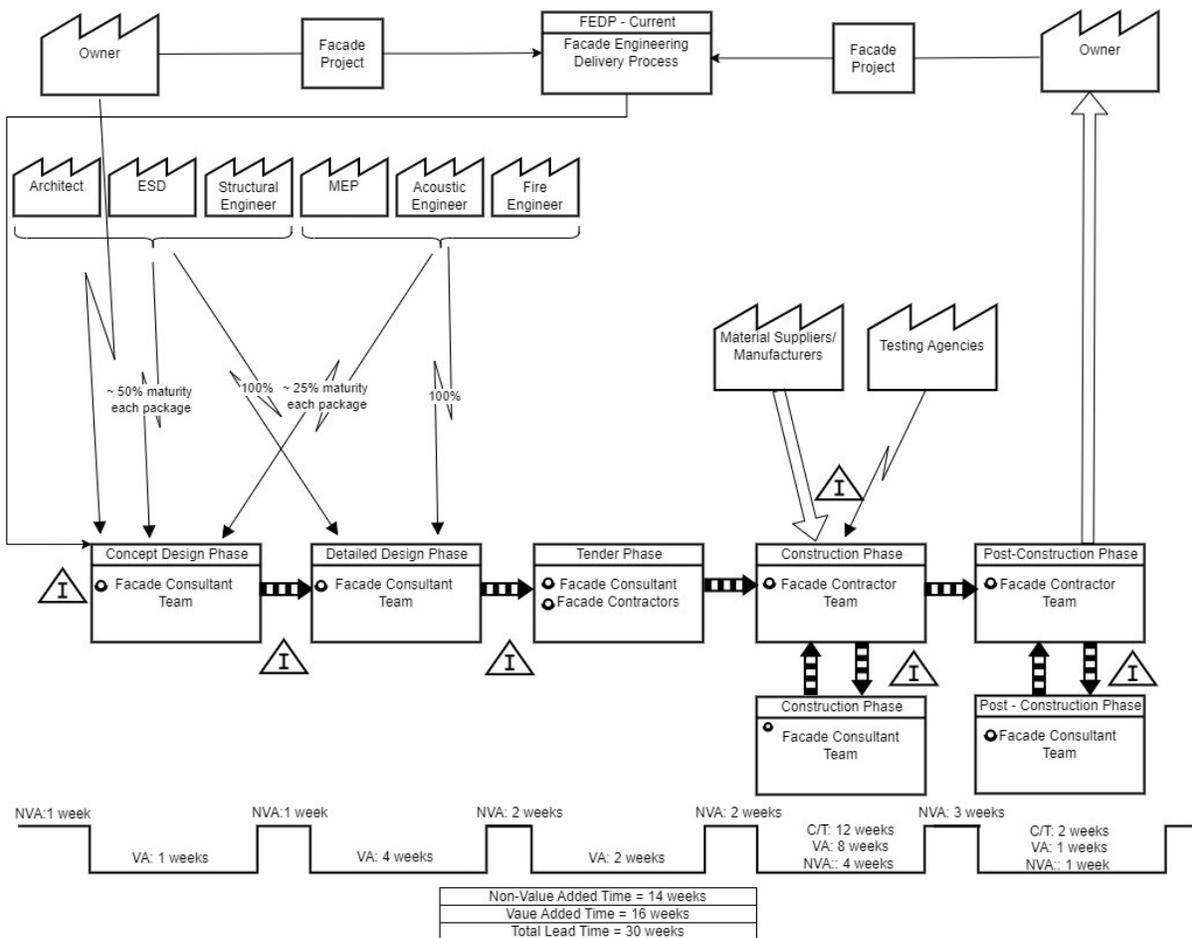
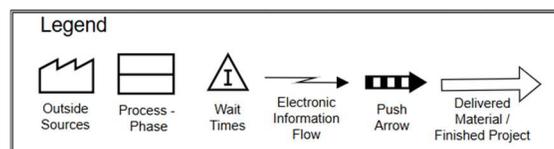


Figure 1 - Current VSM Facade Engineering Delivery Process



4.2 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 façade 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.

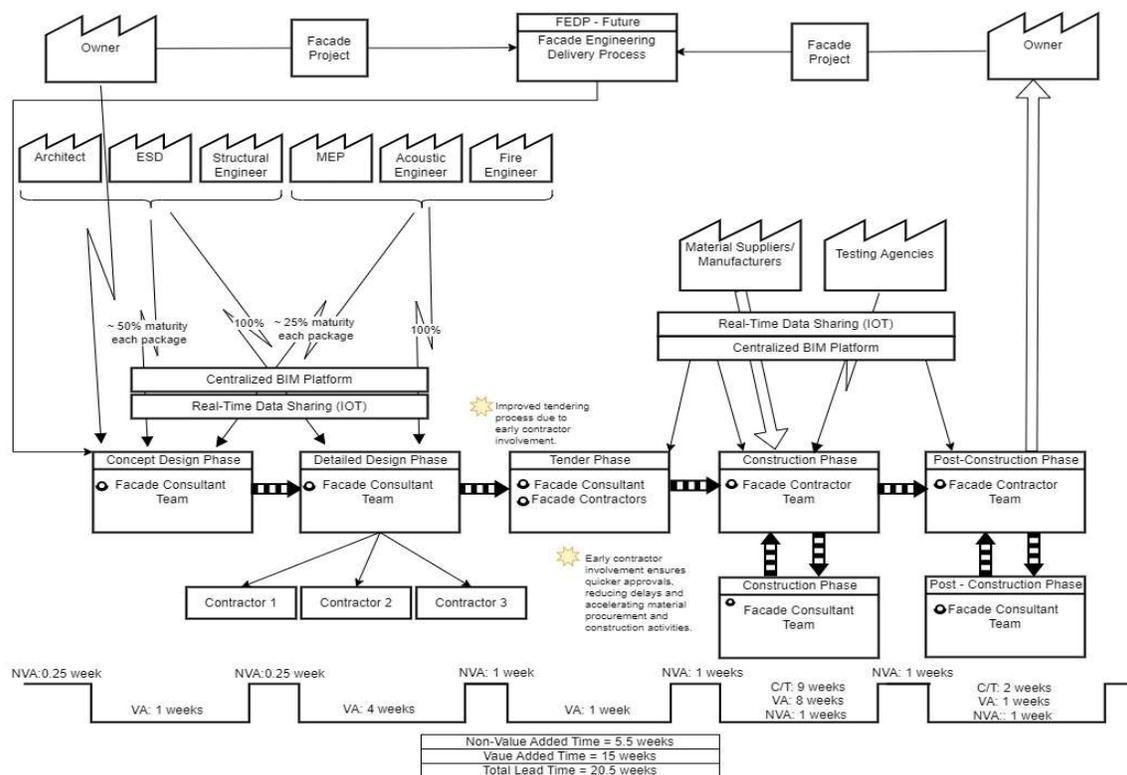


Figure 2 - Future VSM Proposal Façade Engineering Delivery Process

4.3 Discussion

As illustrated in Section 4.1, 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. The existing challenges result in delayed schedules and budget overruns, 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 create a basis for process optimization.

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. 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.

5. 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 generic façade case project familiar to the researchers. The current VSM of the process reveals inefficiencies, such as delays, approval bottlenecks, and rework due to design iterations. The future state VSM proposes solutions to these inefficiencies by early contractor involvement (ECI) and the integration of digital platforms such as BIM and IOT, which demonstrates a significant reduction in non-value-added time and overall project timeline.

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. 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.

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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