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IMPLEMENTATION OF LEAN THINKING TO IMPROVE MASONRY CONSTRUCTION AND DESIGN

Samaneh Momenifar[1], Karl Keyrouz[2], and Farook Hamzeh[3]

ABSTRACT

Masonry construction provides multiple functions with a single element, is cost-effective, durable, and provides a visually appealing finish. In addition, its flexibility in design and reasonable construction cost makes it more attractive. Specifically, characteristics of load-bearing masonry make it a viable choice for residential buildings, hence a viable solution to address housing demands. However, evidence shows this type of building is less desired nowadays due to its reputation as having traditional shapes and low productivity in the construction process.

Lean thinking has been widely applied in the construction industry. However, lean applications in the masonry industry can be widened. In this research, site visits, consultations with industry professionals and stakeholders, and an extensive literature review have been conducted to understand existing problems of design and construction of load-bearing masonry systems in Canada. To address the discovered problems, several lean thinking solutions are proposed with the focus on consideration of complex wall configurations and providing early feedback in the conceptual design stage of masonry buildings. Development of one-piece flow for mortar transportation and generative design tools are two of proposed solutions. Development of intelligent BIM and construction simulation models are presented as future research ideas to validate the proposed lean solutions.

KEYWORDS

Masonry, generative design, simulation, lean thinking.

INTRODUCTION

Compared to other structural systems, masonry's competitiveness is threatened by several myths and assumptions architects hold, such as the high cost of masonry construction and its constrained formal options (Gentry et al., 2009). Waste in the construction industry leads to many problems, such as decreased productivity, cost overruns, schedule delays, and safety issues (Senaratne & Wijesiri, 2008). Also, productivity assessment implemented on the masonry construction process revealed low productivity and waste in this type of construction. The presence of waste negatively affects the value delivered to customers (Abbasian Hosseini et al., 2012). Moreover, more recent studies also show the factors that most affect masonry

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construction are related to rework and lack of safety, required tools or material on a construction site (Svintsov & Abd Noor, 2022) which further leads to waste on construction sites and consequently decreases the value produced for the customer. Implementing lean principles in construction processes can help to identify non-value-adding activities and improve the process, as demonstrated in the masonry industry. Implementing lean construction principles has been shown to reduce waste and improve cycle time and efficiency (Abbasian-Hosseini et al., 2014).

Masonry-bearing walls have a long history in construction, dating back centuries, and have been used in various building types, from simple structures to grand monuments and public buildings (Cross, 1965). During the early 20th century, brick construction for multi-story buildings was primarily replaced by steel and reinforced concrete framed structures, but brick was often used as cladding (Hendry et al., 2017).

The decline in the popularity of masonry construction is believed to have been caused by the introduction of new materials and construction methods, the desire for faster construction, and the development of new load-bearing structures and lightweight facade systems (Sweis et al., 2008). According to our investigation, the decline in masonry construction in Canada is attributed to several reasons, some of which are presented in the literature review. The rest are spotted in construction site visits and consultations with industry practitioners. This paper aims for lean improvements in the current state of masonry in three categories: masonry design, construction, and unit. In masonry design, the design fixation phenomenon is presented as a significant challenge in the current design practice of masonry systems. This leads architects to opt for more straightforward and more conventional solutions instead of innovative ones. Integrating Building Information Modelling (BIM) and generative design can help overcome this by providing architects with a tool to design complex masonry walls that are structurally feasible and constructible. Many innovations have happened in masonry units, including materials, systems, mortar additives, ties, and reinforcements. The recent introduction of masonry units with integrated insulation has gained significant attention in the industry, offering a simpler and more streamlined construction process. The use of alternative masonry blocks that do not require cement and moving towards panelized construction in the design of new masonry units is recommended in this category. In masonry construction, the current implementation of lean in the masonry industry has proven to be effective in reducing waste and increasing efficiency. However, the complexity and variability of wall configurations, especially L-shaped and T-shaped walls, have posed challenges to implementing lean in the masonry industry. The future of masonry construction can be improved using lean thinking steps here. Some of these steps are developing a just-in-time schedule for bricks and mortar components delivery and using pull-driven scheduling when planning the bricklaying of different sections of a building composed of Concrete Masonry Units (CMUs).

LITERATURE REVIEW

Masonry load-bearing walls have a long history of use in construction, dating back centuries. They have been used in many building types, from small, simple structures to grand monuments and public buildings (Cross, 1965). Brick construction for multi storey buildings was replaced by steel- and reinforced concrete-framed structures in the first part of the 20th century, but they were frequently covered with brick (Hendry et al., 2017). The John Root-designed Monadnock Building in Chicago, which stands sixteen stories tall and has walls that are 1.82 meters thick at the base, was "the final triumph of traditional masonry building" in 1891 (Cross, 1965).

It is believed that the introduction of new materials and construction methods, the desire for faster construction with fewer workers on-site, and the development of new load-bearing structures and lightweight facade systems have led to a decrease in the popularity of masonry (Sweis et al., 2008). One of the leading causes of this was that solely empirical criteria were used for proportioning load-bearing walls up until around 1950. It resulted in unnecessarily thick walls that wasted material and space and took a long time to construct (Sinha, 2002). The development of structural codes of practice, which made it possible to determine the required wall thickness and masonry strengths more reasonably, improved the situation of masonry buildings in several countries after 1950. Although initially limited in scope, these standards of practice were based on research projects and building experience. They offered an adequate framework for the design of structures up to thirty stories. The development and enhancement of the various structural codes for masonry structural design over the past 20 years has resulted from extensive research and real-world experience. Because of this, the structural design of masonry buildings is getting closer to being on par with steel and concrete (Hendry et al., 2017).

In terms of architectural design, modern architecture conflicts with masonry. Using steel or concrete frames and curtain wall skins in construction has led to the dematerialization of design, while masonry construction is rooted in using materials. This user has created an ambivalent relationship between modern architecture and masonry (Collins, 1998). In addition, there is a notion that architects are not pushing the boundaries of masonry, even though the masonry business and research community have consistently advanced with improvements. Such improvements aim for new masonry unit types with sustainable and green construction and integrated insulation (Subasic, 2022), structural analysis methodologies, and more effective building procedures (Beall, 2000; Beall & Jaffe, 2003). It has been noted by Heyman (Heyman, 1996) that the decline in masonry as a building material has led to a decrease in expertise and knowledge in masonry design, detailing, and construction, particularly in the use of non-planar forms of load-bearing masonry structures. Researchers (Gentry et al., 2009) claim that the perception of masonry as a conservative and risky building technique when aiming for innovative shapes, combined with a shortage of specialized knowledge and computational tools, limits its acceptance and acceptance ability to compete with other building methods. Therefore, most new masonry buildings use traditional and conservative solutions.

The sequential and complex construction process of masonry buildings causes inconsistent information flows in design and construction. Design management entails managing the flow of information and coordinating individuals and teams involved in the design process (Al Hattab & Hamzeh, 2018). Design workflow consists of transferring information and deliverables between teams and individuals, and it has become more complex due to advancements in design specifications, end-user needs, and technology. The production of large amounts of information and the pressure of deadlines and budgets increases the risk of design errors and conflicts. Poor design flow can lead to several types of waste, including excessive rework and revision cycles, design errors, reduced quality, increased costs, and schedule delays, ultimately decreasing the value generated for end-users (Ballard, 2002).

It is confirmed by industry practitioners in Canada that masonry wall systems are facing competition from other wall systems such as wood, glass, steel clad, and precast (Jordan Kuntz, 2022). According to our site visits and consultations with industry practitioners, there are multiple reasons behind this phenomenon, some of which are mentioned in the literature. In this paper, reasons behind the decline in the prevalence of masonry use are presented into three categories: masonry design, masonry unit, and masonry construction.

METHODOLOGY

Building with masonry requires significant manual labor, and the implementation of innovative solutions needs to be expanded. Another hurdle facing the masonry industry is the unawareness of new masonry forms and construction techniques by professionals in the field. This study evaluates the current construction and design methods used in masonry construction and the possible lean improvements that can be applied in the industry. The authors hypothesize that by looking at the design and construction of masonry systems, it is possible to provide potential lean solutions that will be of value to the industry and the professionals in it. Lean principles have already been implemented in the masonry industry, but their current applications have been limited. As such, this study presents what has been done in the masonry industry to improve the design and construction of masonry systems and the potential possible lean applications. The reviewed literature first identifies the research problems. Then, multiple construction site visits, consultations with masonry industry practitioners, and the conducted literature review formed the basis for recommending lean solutions. These lean thinking solutions are hoped to decrease waste in design and masonry construction practices. The methodology diagram developed by the authors as a research framework is shown below in Figure 1. In the first phase, a literature review on design principles of masonry systems and lean improvement is conducted. Then, several site visits from masonry construction projects and discussions with superintendents and masons are implemented. Consultations with active industry practitioners were the last step of phase 1. During phase 2, authors tried to address the discovered problems with lean solutions, and in the previous phase, future research opportunities for implementation and validation of proposed lean solutions are presented.

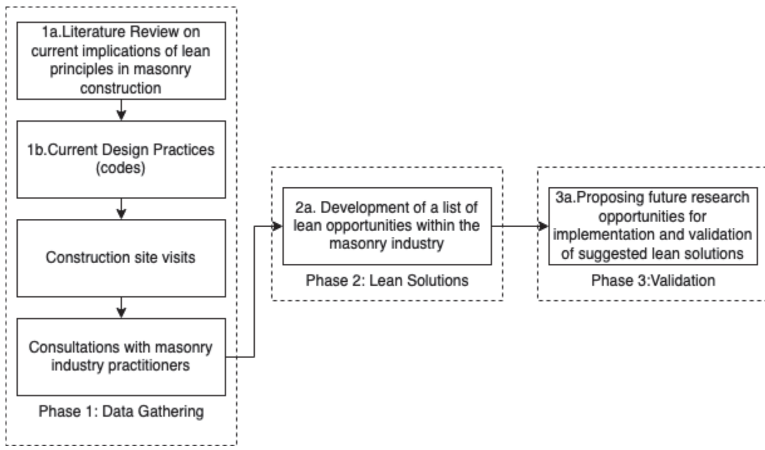

Figure 1: Research Methodology

To develop a list of lean opportunities in the masonry industry, site visits were performed to identify the problems currently affecting masonry productivity and, more specifically, in the bricklaying process. In addition, in a 2-day masonry Hackathon held at the University of Alberta, discussions with industry stakeholders and professionals of diverse backgrounds in naming, structural, thermal efficiency, and robotics brought to light some previously unknown aspects of existing problems in the masonry industry.

MASONRY DESIGN

Researchers claim that a phenomenon known as design fixation (Jansson & Smith, 1991; Purcell & Gero, 2006) is happening in current masonry design due to lack of early feedback: The lack of early feedback during the conceptual design stage can result in uncertainty, leading architects to avoid unusual and potentially more innovative solutions and instead opt for more straightforward and more conventional solutions. This is more likely when the number of parts involved in a problem is high, such as in the case of a masonry wall, cladding system, or tiled roof. Furthermore, the tendency to follow conventional configurations is often justified by adhering to traditional construction wisdom (Cavieres et al., 2009), which can result in a missed opportunity for innovation and progress in the design and construction of masonry structures. Hence, it is essential for architects to have access to the necessary knowledge resources and to receive early feedback during the conceptual design stage to help guide their decisions and minimize the risk of design fixation (Cavieres et al., 2011). The authors conclude that when masonry designers are equipped with constructability knowledge of innovative masonry configurations, the state of masonry in both design and construction will be significantly improved.

However, masonry designers have a limited number of digital tools at their disposal to represent and investigate novel brickwork arrangements. The amount of work architects must spend modeling and detailing a building with hundreds or thousands of masonry components becomes expensive without such technologies (Bettig & Shah, 2001). This means current technological advancements are not being widely adopted into masonry design practice.

BIM is expected to revolutionize the construction industry by introducing more standardization, consolidation, and integration in the construction process. BIM will shift the construction process from being project-based and reliant on unique customer specifications to a more product-based approach, utilizing off-site manufacturing and prefabrication (Heigermoser & de Soto, 2022). BIM will enable the integration of generative design solutions, a design approach many researchers have proved effective in creating more creative masonry wall configurations. Masonry units offer a wide range of configurations and formal results, which can be intensively explored through parametric modeling, making the representation of complex geometries and assemblies easier and more realistic, leading to innovation in the design of masonry buildings. Some research focuses on promoting the use of concrete masonry systems in contemporary design practice by incorporating masonry construction knowledge into the design process through state-of-art computational technologies. The goal is to improve the design and construction processes by enabling the creation, testing, and evaluation of a more considerable number of design alternatives from the start. This way, an important focus will be on building envelopes' formal variability and geometric complexity. The methodology described is a simplified system that helps architects design complex masonry walls in the initial stages of the design process. The system uses continuous updates in a CAD environment and Building Information Model to validate, shape, and bind architectural decisions. Its purpose is to provide architects with a tool to design structurally feasible and constructible walls, giving them confidence in their design decisions (Gentry et al., 2009).

Generative design (GD) is a computational design method that uses algorithms and parameters to generate a range of design solutions based on specified constraints and objectives. The process involves inputting design criteria, such as desired functionality, material properties, and manufacturing limitations, and then allowing the computer to generate and evaluate different design options. The final design solution is chosen based on the best combination of performance, cost, and other factors. Integrating generative design and BIM combines the benefits of both approaches to create a more efficient and effective design process (Nagy, 2020). By combining the intelligent design capabilities of generative design with the automated construction information generation of BIM, the GD-BIM integration can help ensure that the algorithm's designs are feasible and constructible. At the same time, it can enhance the BIM's capabilities in the early design phase by providing more accurate and detailed design information. This results in a more streamlined design process that saves time, reduces errors, and improves overall outcomes (Ma et al., 2021).

BIM and Lean Construction are both approaches that have significantly impacted the Architecture, Engineering, and Construction (AEC) industry. BIM primarily focuses on digital transformation in the construction industry, and Lean Construction focuses on improving the production management process. Studies have shown that the simultaneous application of both approaches can enhance the productivity of projects and improve efficiency (Sacks et al., 2010). It is concluded that implementing the lean-BIM approach in the design process of masonry structures will enable the introduction of non-conventional shapes, which require a smoother construction procedure on construction sites.

MASONRY UNITS

The invention of Portland cement in the early 19th century significantly altered the composition of masonry mortar. It allowed the production of concrete masonry units to replace traditional building materials like brick and stone. This invention marked a turning point in the evolution of masonry construction. Researchers state that most of the changes to masonry in the 20th century have been focused on improving production methods and refining the properties of unit masonry materials, such as making them stronger, lighter, or easier to produce, rather than introducing innovations to the masonry system itself. Such innovations can be listed in four primary groups of products and materials:

1. Masonry units and materials: the building blocks, such as bricks, stone, or concrete masonry units.
2. Masonry systems: the overall construction method, such as load-bearing masonry or cavity wall construction.
3. Mortar additives: ingredients added to mortar to enhance its properties, such as water resistance or workability.
4. Ties and reinforcement: elements such as ties or steel reinforcements provide stability and support to the masonry structure. For example, dry stack masonry units were introduced to eliminate mortar and have smoother construction. Also, Carbon fiber-reinforced plastic (CFRP) ties were brought to this industry to facilitate the reinforcement process and have multiple-wythe masonry wall (Beall, 2000).

Among all innovations introduced in masonry units, units with integrated insulations, such as InsulTech (Figure 2), have gained more attention. Such alternative masonry units can be made from various materials, and their shapes and applications are like traditional masonry units (Subasic, 2022). Constructing these units is simpler and more streamlined than conventional construction methods. However, other aspects of this unit, such as shape and structural reinforcement, are the same as traditional ones.

The main concern with the recently proposed masonry units is their compliance with thermal structural and fire safety codes. Also, according to masonry industry practitioners, the idea of having masonry blocks that do not need cement can be beneficial, as the shortage of cement supplies in Canada has indeed impacted the masonry industry, leading to a lack of masonry units and decreased productivity. Using alternative masonry blocks that do not require cement could solve this problem, allowing the industry to continue operating despite the cement shortage.

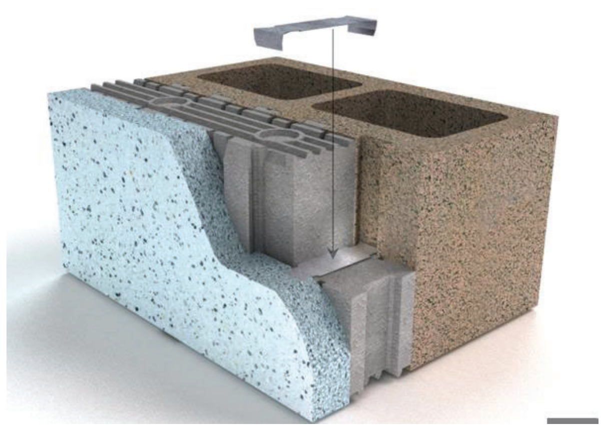

Figure 2: InsulTech masonry unit (Echelon, n.d.)

MASONRY CONSTRUCTION

Based on literature review, it was identified that waste, in all its forms, renders projects slow and vulnerable to conditions on construction sites which consequently restricts the value that can be delivered to the customer. Moreover, waste in all its forms on construction sites reduces flow and value generation (Abbasian Hosseini et al., 2012). Variability and complexity in the construction industry implement lean principles in construction processes, an attractive solution to identify Non-Value Adding (NVA) activities and subsequently improve the process. Implementing lean construction principles in the construction industry, specifically, the masonry industry has been proven to reduce waste in cycle time and efficiency. Using simulation modeling, it was concluded that more than 70% of the bricklaying activities are NVA (Abbasian-Hosseini et al., 2014). Hence, applying lean principles would make the process more efficient by reducing the time needed for NVA activities. Moreover, lean principles have been applied to the bricklaying process using Value Stream Mapping (VSM) to identify waste (Melo et al., 2017). It was determined that reducing transport times and excess inventory reduced NVA time and lead time. Another study (Bajjou & Chafi, 2021) showed that NVA constituted 85.2% of the bricklaying cycle time, with waiting (or idleness) having the most significant share. These studies applied lean principles to identify areas of waste in the masonry industry and change how bricklaying and masonry construction is done on construction sites. Hence, there is a need for more extensive use of lean in the industry. Moreover, such studies fail to include the different and more complex types of wall configurations. Current research also involves the implementation of sustainable solutions, which consists of adding robots on-site to create semi-autonomous bricklaying systems. (Usmanov et al., 2021) creates a digital layout plan for robotic bricklaying. However, such a system only considers orthogonal walls and does not consider more complex wall shapes or configurations.

The data gathered concerning masonry construction was done by multiple site visits of a school gymnasium being built entirely using CMUs as a structural element. The visits aimed to identify the difficulties encountered in masonry construction. During the visits, common types (patterns) of wall configurations using CMU blocks were identified. The goal of the visit was reached after observing the bricklayers perform their work. Therefore, the data gathered was based on the spotting and discerning of patterns of construction the bricklayers would follow. The frequency of those patterns to create different types of wall configurations and based on the current literature review, the most common types of wall configurations were found as shown in Figure 3:

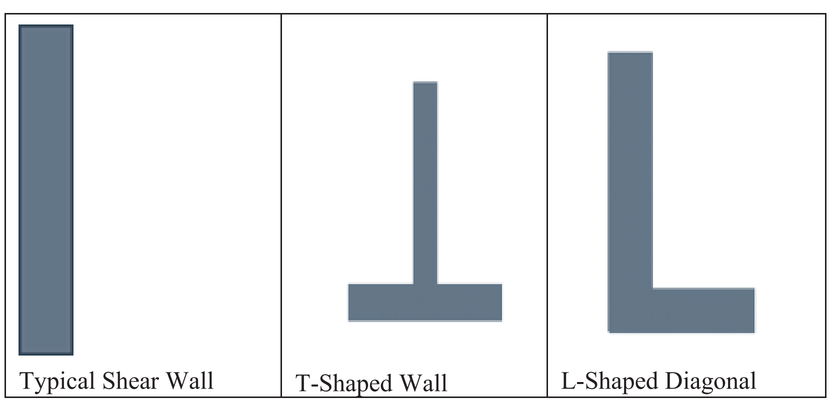

Figure 3: Most common wall configurations

Typical shear walls were found to be the most common type of masonry walls being built. Bricklaying such walls consists of several steps: lift brick, spread mortar, knock, level, and remove excess mortar. CMUs lifting leads to work-related musculoskeletal disorders (WMSDs) due to the repetitive stress of the bricklaying steps on the workers' bodies (Wang et al., 2015). The repetitive motions lead to decreased productivity over time as WMSDs disorders occur. Moreover, the current bricklaying process requires constantly refilling mortar and brick stations at the wall construction sites. The existing masonry practices are done for the different shapes of walls, but specific issues were noticed to emerge in more complex shapes (such as L and T). For L-shaped and T-shaped walls, it was observed that many problems that hinder productivity happen during construction. Most notably, the bonded wall components forming the L or T shape should be built simultaneously due to the presence of the intersection part between the two members forming the shape. Such configurations are complex to build and hence require more time to build than a typical shear wall. In addition, the variability in the geometrical design of masonry walls leads to the difficult reproducibility of such wall-shape configurations on-site. This leads to decreased productivity on construction sites. Moreover, as wall shape configurations become increasingly complex, the quantities of equipment and material needed increase. Indeed, when faced with different structural scenarios (over-opening such as lintels, change in wall thickness, etc.), there is an increase in the time required to perform the bricklaying process.

Moreover, the visits to construction sites show that the identified patterns lack productivity, with construction being highly variable, and are subject to the construction site layout planning done beforehand. Hence, there is a need for the implementation of lean concepts in masonry construction.

LEAN THINKING SOLUTIONS

Masonry construction suffers from problems in productivity and is plagued by a myriad of difficulties ranging from heavy lifting, causing a strain on the Musculo-skeletal system of bricklayers as well as non-optimal construction designs that would take more time to be built, affecting the masonry industry in both the design and construction phases. Current lean improvements in masonry systems have identified many problems impacting the bricklaying process, namely the inventory and transport issues. However, current research fails to consider a holistic integration of all parts of the bricklaying process, whether autonomous, semi-autonomous, or human-driven only, to implement lean solutions and reduce waste.

Based on the findings in the literature and after the multiple on-site visits, we present the opportunities from a lean perspective in this section. Opportunities in masonry construction (Figure 4) focus on bricklaying itself in masonry construction. Applying lean to masonry construction can increase site productivity while reducing the efforts needed for current bricklaying practices. Moreover, using lean methods would enable faster design and construction processes to deliver better value to the customer.

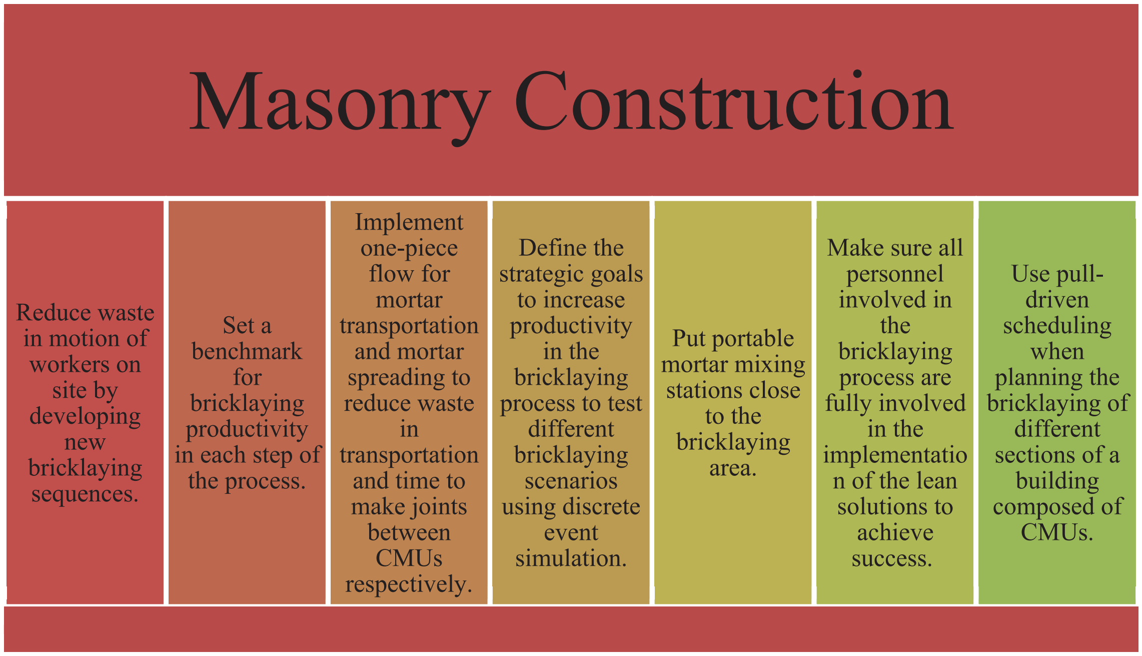

Figure 4: Opportunities in Masonry Construction

Figure 5 shows the wasted opportunities that can be applied in masonry design. Using lean practices in masonry design makes it possible to develop optimal designs in the pre-construction stages of projects. Based on the observations from site visits, having knowledgeable designers on the construction process and labor intensity of different wall configurations can help a smoother construction process. Also, according to discussions with various masonry industry experts, integrating advanced tools with a holistic masonry design approach is missing in current design practice. Here, we present some lean solutions to such problems in masonry design.

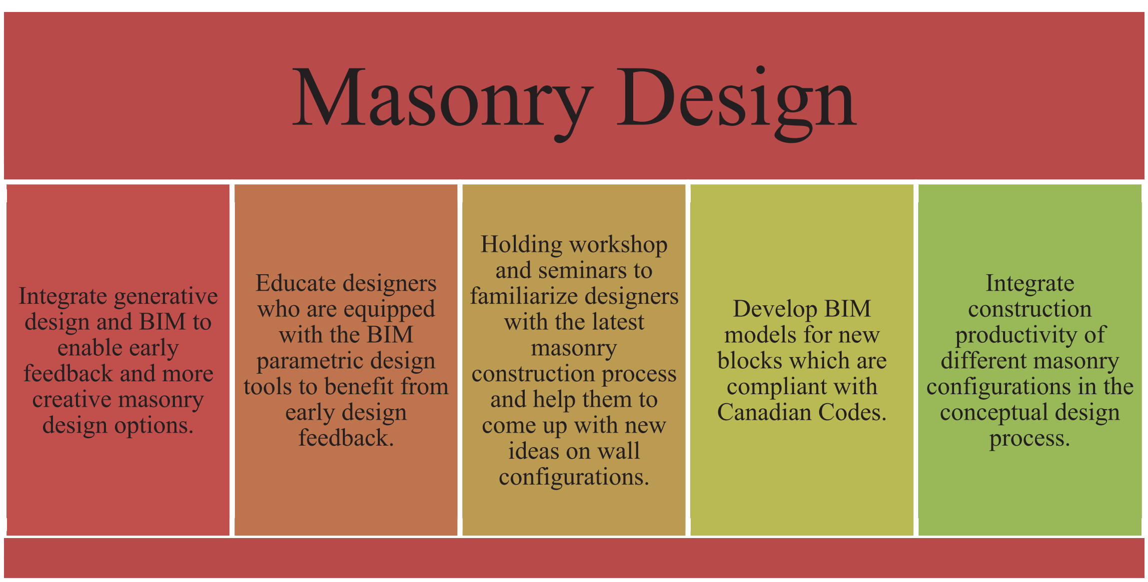

Figure 5: Opportunities in Masonry Design

Lean opportunities can also be applied to masonry blocks by creating blocks with more sustainable materials and better block shapes and designs. Figure 6 shows the lean solutions applied to masonry units:

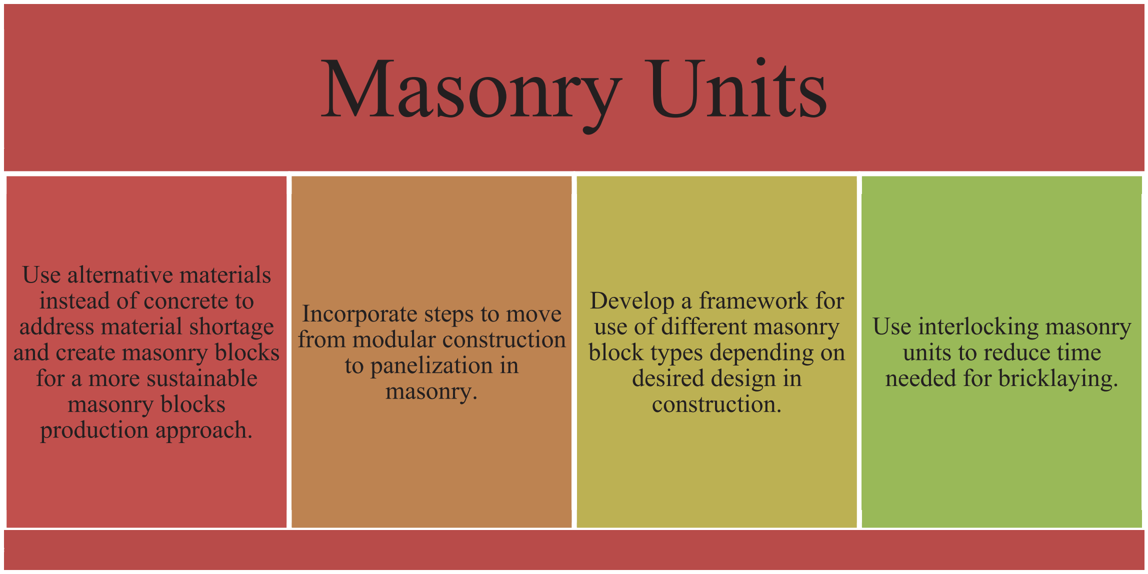

Figure 6: Lean opportunities for masonry units

CONCLUSIONS

Based on the literature review, multiple construction site visits, and discussions with industry practitioners, it has been found that the implementation of lean principles in the masonry industry can reduce waste and improve efficiency. Value Stream Mapping (VSM) and simulation modeling have shown that many bricklaying activities are non-value adding (NVA), with the largest share being waiting. However, current research focuses on orthogonal walls and lacks consideration of more complex wall configurations. L and T-shaped walls are one of the complex shapes that need to be taken into consideration when trying to improve the masonry construction process. Therefore, there is a need for more extensive use of lean principles in the masonry industry. The lack of early feedback during the conceptual design stage can lead to design fixation in masonry design, resulting in architects choosing more straightforward, more conventional solutions instead of more innovative ones. BIM is expected to revolutionize the construction industry by enabling generative design solutions, allowing for exploring a more comprehensive range of design alternatives and improving the design and construction processes. Integrating generative design and BIM can lead to a more efficient and effective design process. At the same time, the simultaneous application of BIM and Lean Construction can enhance the productivity and efficiency of projects. Implementing a lean-BIM approach in masonry design will allow for the creation of non-conventional shapes and a smoother construction process. Future research is needed to validate the effectiveness of proposed lean solutions in improving masonry design and construction. To validate the proposed methods in masonry design, intelligent BIM models can be built to benefit from generative design tools and algorithms in reaching an optimized wall layout design. In construction, we can validate our solutions using Discrete Event Simulation as they allow us to check the effect the implementations have on construction productivity and refine the models and solutions as results of the simulations become available. Moreover, the use of lean principles should not only be limited to orthogonal walls but also to non-orthogonal walls too and a study for finding the root causes of disappearing construction material in Canada should also be further investigated. Recommendations proposed for masonry block improvements can be validated by incorporating new block characteristics and geometry into the intelligent BIM model and masonry construction simulation model.

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REFERENCES

Abbasian Hosseini, A. S., Nikakhtar, A., & Ghoddousi, P. (2012). Flow Production of Construction Processes through Implementing Lean Construction Principles and Simulation.

Abbasian-Hosseini, S. A., Nikakhtar, A., & Ghoddousi, P. (2014). Verification of lean construction benefits through simulation modeling: A case study of bricklaying process. *KSCE Journal of Civil Engineering*, *18*(5), 1248–1260. https://doi.org/10.1007/s12205-014-0305-9

Al Hattab, M., & Hamzeh, F. (2018). Simulating the dynamics of social agents and information flows in BIM-based design. *Automation in Construction*, *92*, 1–22.

Bajjou, M. S., & Chafi, A. (2021). Application of Simulation Modelling for Waste Assessment: A Case Study of Bricklaying Process. *International Journal of Engineering Research in Africa*, *52*, 40–48. https://doi.org/10.4028/www.scientific.net/JERA.52.40

Ballard, G. (2002). Managing work flow on design projects: a case study. *Engineering, Construction and Architectural Management*, *9*(3), 284–291.

Beall, C. (2000). New masonry products and materials. *Progress in Structural Engineering and Materials*, *2*(3), 296–303.

Beall, C., & Jaffe, R. (2003). *Concrete and Masonry Databook*. McGraw-Hill Professional Publishing.

Bettig, B., & Shah, J. (2001). Derivation of a standard set of geometric constraints for parametric modeling and data exchange. *Computer-Aided Design*, *33*(1), 17–33.

Cavieres, A., Gentry, R., & Al-Haddad, T. (2009). Rich Knowledge Parametric Tools for Concrete Masonry Design Automation of Preliminary Structural Analysis, Detailing, and Specifications. *26th International Symposium on Automation and Robotics in Building, Information and Computational Technology*, 545–552.

Cavieres, A., Gentry, R., & Al-Haddad, T. (2011). Knowledge-based parametric tools for concrete masonry walls: Conceptual design and preliminary structural analysis. *Automation in Construction*, *20*(6), 716–728.

Collins, P. (1998). *Changing ideals in modern architecture, 1750-1950*. McGill-Queen's Press-MQUP.

Cross, J. C. (1965). Introduction to Contemporary Bearing Walls. *Proc. National Brick and Tile Bearing Conference*.

Echelon. (n.d.). *Insultech Masonry units*.

Gentry, T. R., Cavieres, A., & Al-Haddad, T. (2009). Parametric design, detailing, and structural analysis of doubly-curved load-bearing block walls. *11th Canadian Masonry Symposium*.

Heigermoser, D., & de Soto, B. G. (2022). Implementing Lean-BIM Duality: Balance between People, Process, and Technology. In *Lean Construction 4.0* (pp. 98–116). Routledge.

Hendry, A. W., Sinha, B. P., & Davies, S. R. (2017). *Design of masonry structures*. CRC Press.

Heyman, J. (1996). The stone skeleton: structural engineering of masonry architecture. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, *3*(33), 133A.

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, *12*(1), 3–11.

Jordan Kuntz. (2022, October 17). *Industry challenges and wall share*. Masonry Symposium.

Liang, J., & Memari, A. M. (2011). Introduction of a panelized brick veneer wall system and its building science evaluation. *Journal of Architectural Engineering*, *17*(1), 1–14.

Ma, W., Wang, X., Wang, J., Xiang, X., & Sun, J. (2021). Generative design in building information modelling (BIM): approaches and requirements. *Sensors*, *21*(16), 5439.

Melo, L. A. P., Lima, V. F. C. de, & Melo, R. S. S. de. (2017). *Value Stream Mapping: A Case Study in Structural Masonry*. 755–762. https://doi.org/10.24928/2017/0167

Nagy, D. ; V. L. (2020). *Generative Design for Architectural Space Planning*. Autodesk University.

Purcell, A. T., & Gero, J. S. (2006). *Design and Other Types of Fixation or Is Fixation Always Incompatible with Innovation?*

Ramamurthy, K., & K.B.Anand. (1999). Techniques for accelerating masonry construction. In *Int. Journal of Housing Science and its Applications* (Vol. 23, Issue 4).

Sacks, R., Koskela, L., Dave, B. A., & Owen, R. (2010). Interaction of lean and building information modeling in construction. *Journal of Construction Engineering and Management*, *136*(9), 968–980.

Senaratne, S., & Wijesiri, D. (2008). *Lean Construction as a Strategic Option: Testing its Suitability and Acceptability in Sri Lanka*. www.leanconstructionjournal.org

Sinha, B. P. (2002). Development and potential of structural masonry. *Ponencia En El Seminario Sobre Paredes de Albañilería, Lourenco y Souza, Porto, Portugal*.

Subasic, C. (2022). A Survey of Innovations in Masonry Units Addressing Sustainability. *2022 Masonry Symposium: Advancing Masonry Technology*, 122–137.

Sweis, G. J., Sweis, R. J., Abu Hammad, A. A., & Thomas, H. R. (2008). Factors affecting baseline productivity in masonry construction: a comparative study in the US, UK, and Jordan. *Architectural Science Review*, *51*(2), 146–152.

Trubiano, F., Dessi-Olive, J., & Gentry, R. (2019). Masonry tectonics: Craft, labor, & structural innovation in architectural education. In *Structures and Architecture: Bridging the Gap and Crossing Borders* (pp. 431–438). CRC Press.

Usmanov, V., Illetško, J., & Šulc, R. (2021). Digital Plan of Brickwork Layout for Robotic Bricklaying Technology. *Sustainability*, *13*(7), 3905. https://doi.org/10.3390/su13073905

Wang, D., Dai, F., & Ning, X. (2015). Risk Assessment of Work-Related Musculoskeletal Disorders in Construction: State-of-the-Art Review. *Journal of Construction Engineering and Management*, *141*(6). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000979