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Enhancing Efficiency in Light-Gauge Steel (LGS) Prefabrication: A Strategic Workflow Optimization

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Abstract: The Light-Gauge Steel (LGS) system is a construction technology that employs cold-formed steel as its primary material. This technique involves pressing the steel at extremely low temperatures to create thicknesses ranging from 0.5 to 3 mm. It can be carried out in a controlled factory environment with greater feasibility. However, the lack of streamlined processes for its implementation poses significant challenges in realizing its full potential. This study aims to both develop an optimized prefabrication workflow for LGS components and select the most suitable software solutions to support and enhance this workflow. The initiative represents a significant step forward in the efficient use of LGS, focusing on the integration of cutting-edge design and manufacturing technologies. A mixed-method research methodology was employed that included conducting on-site machinery observation, meetings with industry experts, exploration of software options, evaluation of software solutions, and model testing. Two leading software solutions, FrameBuilder-MRD and StrucSoft's MWF Pro Metal, were identified for their exceptional capabilities in LGS design and fabrication. These tools stood out for their automated design features, material optimization, and comprehensive integration with Building Information Modeling (BIM), addressing the critical needs of the prefabrication process. The implementation of this software is expected to significantly refine production processes, enhance operational efficiency, and solidify the role of advanced prefabrication methods in the construction sector. This paper details the selection process for software solutions, emphasizes the synergy between technological innovation and practical application, and outlines strategic recommendations for adopting an effective LGS prefabrication workflow. It highlights the important role of technology in advancing construction practices, offering insights into achieving greater efficiency and sustainability in the industry.

Keywords: Light-gauge steel (LGS); prefabrication; workflow optimization; software solutions; off-site construction (OSC)

1 INTRODUCTION

In recent decades, the construction sector has experienced remarkable growth boosted by technological advancements. Prefabrication, representing a major part of this industry, has gained widespread acceptance on a global scale (Chippagiri et al. 2022). In this dynamic context, the widespread adoption of light-gauge steel (LGS) components has grown significantly as researchers have extensively studied its structural properties and characteristics over time (Halabi and Alhaddad 2020). With an understanding of the potential of such an innovative approach, Atlantic Roll Forming, a company based in Moncton, Canada known for offering cutting-edge construction solutions, has invested in a state-of-the-art roll-forming machine to capitalize on future growth. The company is not only entering the LGS prefabrication market, but also embracing advanced manufacturing techniques by making this move. In collaboration with the University of New Brunswick's Off-site Construction Research Centre (OCRC), Atlantic Roll Forming launched a project aimed at transforming the prefabrication process of LGS components. The objective of this initiative was to identify software solutions that could optimize the design and production processes. A seamless integration of digital fabrication and traditional construction practices was crucial to the success of the project.

To identify LGS prefabrication software, a comprehensive methodology was developed, including a systematic review of existing software solutions, industry consultations, and an examination of the most suitable software. There were two leading choices: FrameBuilder-MRD and StrucSoft's MWF Pro Metal, both of which offered unique features and capabilities tailored to LGS fabricators' specific needs. In addition to identifying optimal software solutions, the collaboration focused on refining and optimizing workflows, ensuring a seamless transition from design to real world implementation. This paper outlines the findings of the collaborative effort, detailing the systematic approach to software selection, the evaluation of software solutions, and the development of a comprehensive workflow for LGS prefabrication. Through this exploration, Atlantic Roll Forming and UNB OCRC aim to further the field of OSC by providing insights and recommendations that will guide future work. As a result of this initiative, LGS components will be manufactured to the highest standards of quality and sustainability, setting a new benchmark for excellence in prefabrication.

2 LITERATURE REVIEW

In modern times, technology is rapidly evolving across various sectors, yet construction remains largely traditional. Prefabrication, or prefab, has emerged as a solution to enhance construction methods. Prefab offers benefits like better time management, cost savings, improved quality, increased productivity, and safety measures (Chippagiri et al. 2022). Light-gauge steel (LGS), also known as cold-formed or cold-rolled steel, is a material shaped at low temperatures to enhance and optimize construction processes (Reza, Amin, and Chowdhury 2022). This section reviews the existing literature on LGS prefabrication, the role of software in enhancing construction workflows, and the advancements in roll forming technology that underpin this modern approach to construction.

2.1 Light gage steel (LGS) and prefabrication

The construction industry's rapid expansion necessitates more advanced structures, making the choice of construction materials crucial for ensuring benefits, quality, and economic efficiency. Steel is favored in construction for its numerous advantages, including its superior sustainability and minimal environmental impact over its entire life cycle. As a fundamental material, steel is essential for various sectors including local energy production, transportation, and both commercial and residential construction (Nadya and Usman 2018). According to Reza, Amin, and Chowdhury (2022) steel has been employed in residential construction for 70 years, with numerous outstanding examples of its use globally. In the construction of steel structures, there are primarily two varieties of steel used to fabricate structural components: hot-rolled steel (HRS) and cold-formed steel (CFS) (Abbas, Sause, and Driver 2006). CFS structures are created by shaping flat steel sheets into various forms that enhance their structural and functional performance beyond that of flat sheets alone. These structures are characterized by their thin walls and high strength-to-weight ratio, making them known as "light gauge steel (LGS) members." The use of CFS in construction can lead to reduced labor costs and economic advantages, thanks to the lightweight and easy-to-handle nature of these materials (Lawan et al. 2015; Hancock 2016). Figure 1 shows the use of light steel frames in a villa structure.

Figure 1: Prefabricated Light Steel Frame House Villa Structure (https://www.steelfabricat.com/)

A study by Reza, Amin, and Chowdhury (2022) investigates the benefits and obstacles of employing light-gauge steel in the construction of affordable housing, examining its efficiency, cost savings, and the possibility of substituting conventional construction techniques based on an in-depth review of multiple research projects on its usage in the construction sector. Jelčić Rukavina et al. (2022) also discussed a broader implication of adopting such materials and techniques by focusing towards understanding the environmental sustainability of LGS within the construction industry.

In studies by (Kumar 2015; Reza, Amin, and Chowdhury 2022), they investigate the benefits and obstacles of employing LGS in the construction of affordable housing, examining its efficiency, cost savings, and the possibility of substituting conventional construction techniques based on an in-depth review of multiple research projects on its usage in the construction sector. Building upon this, Jelčić Rukavina et al. (2022) explores the broader implications of adopting such materials and techniques, particularly focusing on the environmental sustainability of LGS within the construction industry. Extending the conversation further, Kumar. (2015) delves into the practical applications and advancements in the field, demonstrating how light gauge steel frames are increasingly utilized in both load-bearing and non-load-bearing parts of commercial and residential structures. This work underscores the significance of employing software tools like STRAP for the study and design of light gauge steel structures, reflecting the sector's evolution towards more livable, sturdy, safe, economical, and environmentally friendly construction methods.

Building on these insights, it becomes pertinent to delve deeper into the specific category of Cold-Formed Steel (CFS) sections, as explored in Bari, S.Vigneshkannan, and P.Easwaran (2017). This study expands upon the advantages of CFS in the construction industry, showcasing its widespread use in industrial building components worldwide and highlighting the significant benefits of CFS over Hot Rolled Steel (HRS) sections.

Through the lens of these studies, it becomes evident that the integration of innovative design software and sustainable materials like LGS is pivotal for the future of construction, merging efficiency with ecological responsibility. However, according to different literature challenges remain in the widespread adoption of LGS, including the need for specialized design software and fabrication equipment.

2.2 Software integration in construction workflows

According to Graser et al. (2021) digital fabrication is a methodology involves integrating manufacturing geometries into the design phase to improve design-to-production communication. The digital fabrication process can be divided into four primary phases: (1) the design phase, (2) the preparation phase, (3) the fabrication phase, and (4) the assembly phase. The effectiveness and specifics of each phase are shaped by the machines used, the materials selected, and the software applications employed (Tran O'Leary and Peek 2019).

The integration of Building Information Modeling (BIM) and Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) software in construction workflows represents a significant leap forward in addressing the complexities of prefabricated construction (Kumar 2015). These technologies facilitate the seamless transition from design to fabrication, enhancing accuracy, and reducing waste (Navaratnam et al. 2022).

Within the field of digital manufacturing, 3D printing, CNC milling, and laser cutting stand out as prevalent methods, each requiring a distinct method for preparing files (Tran O'Leary and Peek 2019). The process for CNC milling file preparation unfolds through various stages: (1) starting with the development of a 2D or 3D architectural design via CAD software, (2) converting the CAD design into STL format, (3) translating the STL file into machine-readable language (G-code), (4) tailoring the G-code based on the specific machine configuration, (5) transferring the G-code file to the CNC milling machine (Gamal et al. 2023).

Notably, according to a study done by Gamal et al. (2023) computational software is one of the factors that need to be taken into account while integrating digital fabrications techniques into the design process, so evaluating different software options have been identified instrumental in streamlining the LGS design and production process, though research indicates a need for further optimization and customization to meet diverse project requirements.

2.3 Advancements in roll forming technology

The different types of CFS have specific applications in different parts of buildings, such as main walls, shear wall panels, roof elements, etc. These types differ from each other by the shape of the profiles, which are formed in cold rolling machines (Jelčić Rukavina et al. 2022). According to different studies such as Gamal et al. (2023) the evolution of roll forming technology has been pivotal in enabling the efficient production of LGS components. Recent innovations have focused on improving machine flexibility, speed, and integration with CAD/CAM systems, thereby enhancing the overall efficiency of the prefabrication process. Different studies have demonstrated the potential for these technologies to revolutionize LGS manufacturing, although they also note the importance of continuous improvement and adaptation to new software developments.

2.4 Gap in literature

While existing research provides valuable insights into the benefits and challenges of LGS prefabrication, software integration, and roll forming technologies, according to different literature there remains a gap regarding the selection of software options for LGS design and production, particularly in the context of their integration with roll forming equipment (Gamal et al. 2023). Furthermore, there is a lack of detailed case studies that document the practical implementation of these technologies in a real-world setting, highlighting the need for research that bridges theory and practice. This study aims to fill the identified gaps by analyzing software solutions for LGS prefabrication and their integration with advanced roll forming machinery. This research provides a unique case study on optimizing LGS prefabrication workflows, thereby contributing valuable practical insights to the body of knowledge in the field.

3 METHODOLOGY

This study adopts a mixed-methods research approach to comprehensively evaluate software options for LGS prefabrication, integrating both qualitative and quantitative analyses. The research unfolds in two main phases, addressing the objectives through a detailed investigation of software capabilities and their practical application in roll forming technology. Figure 1 shows the methodological workflow of this study.

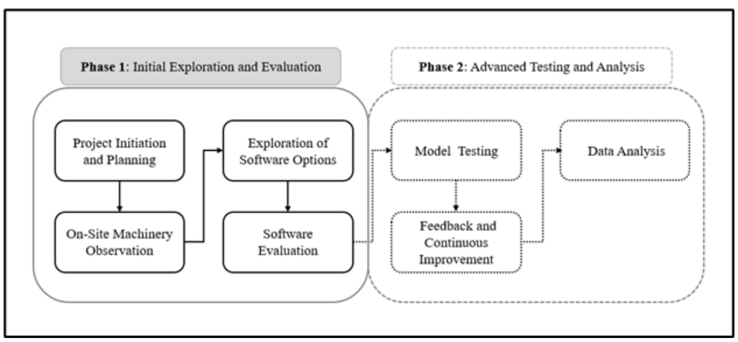

Figure 2: Methodological workflow

3.1 Phase 1: Initial exploration and evaluation

The project started with a series of meetings between researchers from UNB OCRC and stakeholders from Atlantic Roll Forming to outline the project's scope, objectives, and deliverables. These discussions facilitated a mutual understanding of the expectations and established the groundwork for the collaborative effort. Researchers conducted on-site observations at Atlantic Roll Forming's facility to gain firsthand insights into the operational capabilities of the newly acquired roll forming machine. This phase involved documenting the machine's technical specifications, operational workflow, and potential integration points for CAD/CAM software solutions. The exploration phase involved a comprehensive literature review and market analysis to identify available software solutions that could potentially meet the project's needs. Criteria for software selection were developed based on the unique requirements of LGS prefabrication, including compatibility with the roll forming machine, ease of use, feature set, and cost-effectiveness. A multi-criteria evaluation framework was established to assess each software option. This framework considered several key factors illustrating in table 1.

Table 1: Evaluation factors for software selection

N	Factors	Description
1	Integration with Roll Forming Machines	The ability of the software to directly interface with the roll forming machinery, facilitating a seamless flow of data from design to production
2	Efficiency in Generating Shop Drawings and Production Information	The software's capability to accurately and efficiently produce detailed shop drawings and material cut lists.
3	User-Friendliness	The ease with which users can learn and utilize the software, including the availability of training resources and support.
4	Customization and Flexibility	The extent to which the software can be customized to fit specific project requirements and adapt to various design challenges.
5	Cost-Effectiveness	The overall value offered by the software, considering both upfront costs and long-term benefits in terms of efficiency and productivity gains.

Software options were evaluated through a combination of product demonstrations, interviews with industry experts, and trial usage when possible. This hands-on approach allowed the research team to assess the practical utility of each software solution in real-world scenarios.

3.2 Phase 2: Advanced Testing and Analysis (Future Work)

In the forthcoming phase, the research will extend into model testing, where chosen software solutions will be rigorously tested through simulations of the LGS prefabrication process, employing project-specific parameters to assess performance in creating precise and efficient production outputs.

An iterative feedback loop with Atlantic Roll Forming's design and production teams will be established to refine the software selection and workflow optimization continually. This process is designed to ensure the chosen solutions effectively meet the practical challenges of implementation.

Finally, the research will involve a detailed analysis of both qualitative and quantitative data. Statistical methods will be used to examine software evaluation and model testing outcomes, focusing on efficiency, accuracy, and productivity metrics. Concurrently, stakeholder feedback will undergo thematic analysis to uncover insights into user experiences, integration challenges, and areas for improvement.

4 RESULTS

The research aimed to identify and implement the most suitable software solutions for the prefabrication of LGS components, with an emphasis on optimizing the workflow from design to production. The evaluation process identified two leading software solutions, FrameBuilder-MRD and StrucSoft's MWF Pro Metal, as the most promising for Atlantic Roll Forming's requirements. The assessment criteria included integration with roll forming machines, efficiency in generating shop drawings and production information, user-friendliness, customization and flexibility, and cost-effectiveness. Table 2 illustrates these assessment factors in evaluating FrameBuikder-MRD and Strucsoft's MWF pro metal software.

Table 2: Software evaluation assessment for FrameBuilder- MRD and StrucSoft’s MWF Pro Metal

N	Factors	FrameBuilder-MRD	StrucSoft's MWF Pro Metal
1	Integration with Roll Forming Machines	Direct data transferring.	Requires additional steps or plugins for seamless data transfer.
2	Efficiency in Generating Shop Drawings and Production Information	Semi- automated production drawings, limitations for designing roof truces.	Automated production drawings within Autodesk Revit, with robust BIM integration.
3	User-Friendliness	Good, with automated design tools enhancing the design process.	Steep initial learning curve but facilitated by Autodesk Revit environment once mastered.
4	Customization and Flexibility	Offers some customization and flexibility but may be limited by integration challenges.	Extensive customization options available, especially beneficial for complex projects.
5	Cost-Effectiveness	More affordable than StrucSoft's MWF Pro Metal, offering a cost-effective solution without compromising essential functionalities.	More expensive than FrameBuilder-MRD, which may impact budget considerations for some projects.

FrameBuilder-MRD demonstrated significant strengths in automated design tools and material optimization, facilitating efficient design processes and material usage. However, limitations were noted in its integration capabilities with specific roll forming machines and handling of complex geometries.

StrucSoft's MWF Pro Metal, operating within Autodesk Revit, offered robust BIM integration, automated production drawings, and extensive customization options. Challenges were identified in the initial learning curve and the need for additional steps or plugins to achieve seamless data transfer to roll forming machinery.

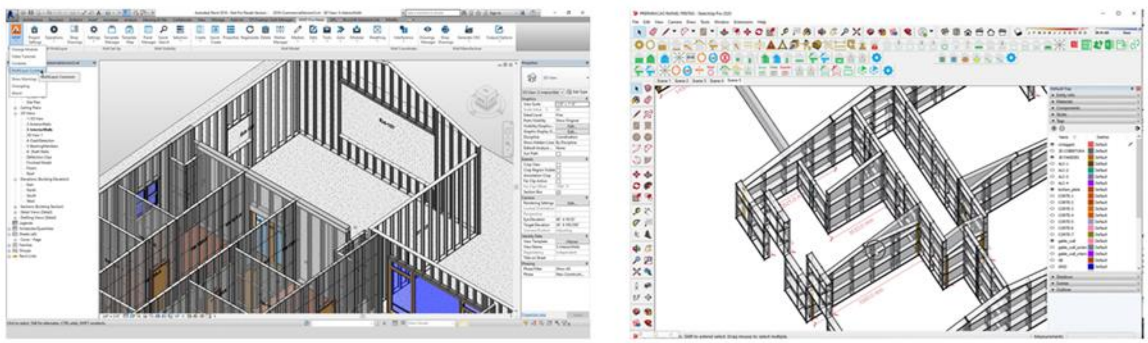

Figure 3: Screenshots of modeling software interfaces.
left, StrucSoft's software. right, FrameBuilder-MRD.

4.1 Workflow optimization recommendations

Based on the evaluation, several recommendations were made to optimize Atlantic Roll Forming's LGS prefabrication workflow:

- **Adopt a hybrid software approach**: Utilize FrameBuilder-MRD for initial design phases due to its user-friendliness and material optimization features, and leverage StrucSoft's MWF Pro Metal for detailed modeling and integration with BIM processes.

- **Custom integration development**: Invest in the development of custom plugins or tools to enhance the data transfer capabilities between StrucSoft's MWF Pro Metal and the roll forming machines, addressing the identified integration challenges.

- **Comprehensive training program**: Implement a tailored training program that covers both software solutions, with a focus on maximizing their respective strengths and addressing any usability or integration issues.

5 DISCUSSIONS

LGS buildings are globally acknowledged, particularly in the USA, Australia, and Japan, as the optimal construction system capable of attaining minimal energy requirements (Rodrigues et al. 2018). According to (Jelčić Rukavina et al. 2022), this is due to the system being very flexible, the potential for innovation and more use of better insulation materials in building, which, along with different ways of building, helps save more energy. So, the exploration of software solutions for the prefabrication of LGS components represents a critical step towards enhancing efficiency, accuracy, and sustainability in the construction industry. This study's findings underscore the nuanced considerations involved in selecting software that aligns with specific production requirements and objectives. The discussion delves into the implications of these findings, challenges encountered, and avenues for future research.

5.1 Implications of software selection

As stated by Liu and Zou (2021) the design stage in a prefabrication process starts by using Computer-Aided Design (CAD) software to create a virtual model that can be either a 2D or 3D design, so the selection of FrameBuilder-MRD and StrucSoft's MWF Pro Metal reflects a strategic approach to leveraging technology in the prefabrication process. The strengths of FrameBuilder-MRD in automated design tools and material optimization are particularly relevant for early stages of design, where speed and efficiency are paramount. Furthermore, StrucSoft's MWF Pro Metal offers deep integration with BIM processes, enhancing collaboration and precision in later stages of design and fabrication. According to Liu and Zou (2021) over the past decade, Building Information Modelling (BIM) has established itself as an effective digital platform for generating, storing, retrieving, sharing, and showcasing construction project data. Additionally, BIM is recognized as a critical process that facilitates the coordination and integration of multi-disciplinary tasks across the entire lifespan of a building and its elements. This hybrid approach illustrates the potential for diverse software solutions to complement each other, addressing different facets of the prefabrication workflow. This is also confirmed by Navaratnam et al. (2022) technological progress has enhanced productivity and reduced waste, crucial for its broad adoption in the prefabricated construction sector. Shorter building periods, improved quality management, enhanced durability, and less disturbance at construction sites have been advantageous.

5.2 Integration challenges and solutions

A significant challenge identified in the study was the seamless integration of software solutions with roll forming machinery. As stated by Hamid, Tolba, and El Antably (2018) The roll forming machine operates based on instructions from CAM software, executing the necessary machining tasks in an exact order to create the specified prototype. It is important to mention that, despite the advanced capabilities of both FrameBuilder-MRD and StrucSoft's MWF Pro Metal, the need for manual adjustments and custom development work points to a gap in the market for fully integrated solutions. Addressing this gap requires close collaboration between software developers, machinery manufacturers, and end-users to co-develop integration tools that cater to the specific needs of the LGS prefabrication industry.

5.3 Training and support for technological adoption

Keeping up with fast-changing technology is a big challenge for the prefab industry. As tech like automation and robotics keep getting better, prefab needs to keep up (Chippagiri et al. 2022). This ties into the need for thorough training and support. Specifically, learning to use complex software like StrucSoft's MWF Pro Metal shows why having customized training is crucial. This helps users make the most out of the software's features. Ongoing support from software vendors, in the form of updates, troubleshooting, and customization services, is also crucial for adapting to evolving project requirements and technological advancements.

5.4 Future directions in LGS prefabrication technology

Looking ahead, the field of LGS prefabrication stands at the cusp of significant technological advancements. The integration of artificial intelligence (AI) and machine learning (ML) into design and fabrication software offers promising avenues for further automation, optimization, and error reduction. Additionally, the development of more sophisticated integration platforms could facilitate real-time data exchange between software systems and manufacturing equipment, streamlining the prefabrication process from concept to completion. Building on this, research has shown that Building Information Modeling (BIM) can greatly benefit all stages of construction projects, especially when it comes to precast elements. BIM has been proven to reduce design costs by up to 30%. Moreover, combining BIM with the Internet of Things (IoT) not only enhances project operations but also aids in monitoring the structure's condition over its lifetime through the use of sensors and data analysis (Lopes et al. 2016). This shows how digital technologies are crucial in making LGS prefabrication more effective and sustainable.

5.5 Limitations of the study

This study's findings are subject to certain limitations, including the focus on a specific set of software solutions and a single prefabrication facility. Future research should consider a broader range of software options and evaluate their performance across different operational contexts. Additionally, the long-term impacts of software selection on project outcomes, including cost, time, and quality, warrant further investigation.

5.6 Contributions to the field

By providing a detailed evaluation of software solutions for LGS prefabrication and highlighting the importance of integration and training, this study contributes valuable insights to the field of construction technology. The recommendations for a hybrid software approach and the emphasis on customized integration solutions offer practical guidance for industry professionals seeking to optimize their prefabrication workflows.

6 CONCLUSIONS

This study was an exploratory journey to identify and evaluate software solutions capable of optimizing LGS component prefabrication. A critical step toward efficiency and innovation in the construction industry. Through a collaborative effort between Atlantic Roll Forming and UNB OCRC, FrameBuilder-MRD, and StrucSoft's MWF Pro Metal emerged as leading software solutions, each offering unique advantages for the design and fabrication of LGS structures. The evaluation process underscored the importance of a hybrid approach, leveraging the strengths of different software solutions to address various facets of the prefabrication workflow. The findings reveal that while advanced software solutions significantly contribute to LGS prefabrication efficiency and accuracy, challenges remain in achieving seamless integration between design software and roll-forming machinery. Addressing these challenges requires technical solutions and ongoing training and support. This is to ensure that users can fully leverage the capabilities of these tools.

The study contributes to the field of construction technology by highlighting the potential for integrating software solutions into LGS prefabrication processes. It offers practical insights into selecting and implementing software tools. It emphasizes the need for a balanced approach that considers both the technical capabilities of the software and the practical realities of the prefabrication workflow. Furthermore, the research emphasizes the importance of collaboration between industry and academia for technological innovation and advancement.

Looking forward, the study identifies several avenues for future research, including the investigation of artificial intelligence (AI) and machine learning (ML) technologies to further automate and optimize the design and fabrication processes. Exploring the development of more sophisticated integration platforms could also yield significant benefits, facilitating real-time data exchange and enhancing the overall efficiency of the prefabrication workflow. Additionally, broader studies involving multiple prefabrication facilities and a wider range of software solutions could provide a more comprehensive understanding of the factors influencing the successful integration of technology in LGS prefabrication. Such research would contribute to the development of best practices and guidelines for the adoption of advanced software solutions in the construction industry.

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