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INTRODUCTION

The construction industry is not doing enough to embrace off-site modular construction. It is a missed opportunity for optimized energy efficiency because prefabricated exterior wall envelopes are lower in cost and faster and easier to install.¹⁻² Factory off-site construction offers improved safety for construction workers because work is done in a controlled environment, but lack of intent, understanding, and data is also a missed opportunity for enhancing worker safety.³ My research looks specifically at the prefabricated wall exterior envelope in the context of safety.

Research Question:
Off-site factories build with ease of energy efficiency and lowered carbon emissions, but is the process safer?

Motivation: Encourage prefabricated wall envelope in factory vs. site construction

- Energy efficiency
- Lowered carbon emissions
- Construction worker safety

BACKGROUND

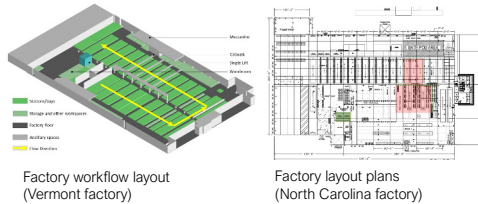
Prefabricated wall exterior envelope

Exterior Insulation and Finish System (EIFS)

1. Metal framing
2. Substrate
3. Wall proofing
4. Adhesive
5. Foam insulation
6. Mesh
7. Base coat
8. Primer
9. Finished texture
10. Water proofing

Source: <https://www.stocorp.com/prefabricated-wall-panels/>

Method: Literature review and observation studies of two off-site factories



Source: Images by NREL staff, Dr. Naveen Kumar Muthumanickam and Shanti Pless

Outcome

- Predict and mitigate workforce safety concerns during construction of energy-efficient, low-carbon exterior envelope
- Workforce safety evaluation framework for modular builders and prefabricators to follow

Ease of energy efficiency integration⁴

- Reduced construction time
- Higher quality control
- Cost savings
 - Smaller, lighter install equipment and machinery
 - Insulation technology – effective moisture barrier

Lowered carbon emissions⁵

- Cuts down on waste from construction process by making better use of materials
- Buy material at exact lengths, avoid overbuying
 - Decrease vehicular transportation to and from construction site

Construction worker safety⁶

- Highly skilled tradesmen
- Fewer workers leads to decreased accidents
- Easy access to wear appropriate safety equipment
- Provide high-quality, well-maintained tools
- Avoid injuries due to heavy lifting
- No scaffolding needed in a factory
- Work is elevated to optimal working height – avoids injuries or mistakes caused by kneeling or bending
- Fixed, directional task lighting eliminates shadows and maintain precise tolerances
- Work takes place in a fully enclosed, well lit, weather protected factory
- Work in progress moves from one station to next via roller conveyors
- Automation of assembly line⁷
 - Improved working conditions
 - Improved productivity and safety performance

RESULTS

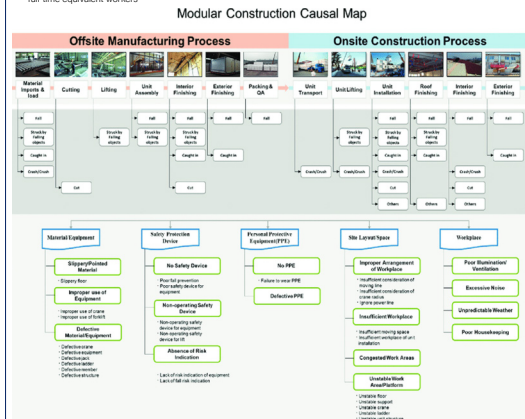
Safety comparison findings in prefabricated and modular construction



Modular and prefabricated construction are perceived to be safer, but the accident rates are much higher than in the general construction and manufacturing industries.

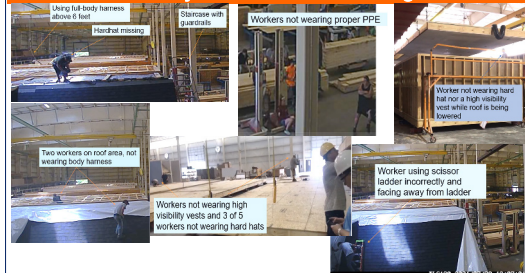
Source: Gilso, Jeong, et al. (2022) Analysis of safety risk factors of modular construction to identify accident trends, Journal of Asian Architecture and Building Engineering, 21.3, 1046-1052. <https://www.tandfonline.com/doi/full/10.1080/13467581.2021.1977441>

The incidence rates represent the number of injuries per 100 full-time equivalent workers



Source: Gilso, Jeong, et al. (2022) Analysis of safety risk factors of modular construction to identify accident trends, Journal of Asian Architecture and Building Engineering, 21.3, 1040-1052. <https://www.tandfonline.com/doi/full/10.1080/13467581.2021.1877441>

Factory observational findings



Source: Photos by NREL staff, Dr. Naveen Kumar Muthumanickam and Shanti Pless

CONCLUSION



Solutions to decrease accidents in off-site prefabricated construction⁸

- Safety training for workers
- Provide movable kiosks with PPE at workstations
- Ensure tools are well-maintained
- Place safety posters in visible locations

Additional Safety Measures

- Need for specialized safety management
- Assist safety managers to understand safety risk factors and make prompt safety decisions
- Predict probability of accidents
- Develop strategy to reduce accidents
- Prioritize risk factors
- Control unsafe conditions
- Use of automated machinery

Canvas Robotic Drywall Finishing Tool



Eliminates:

- Fall risks working at elevated heights
- Exposure to airborne particulates
- Strenuous repetitive motions

Source: Weimer, Pablo, Rully, Ahmad, and Mohamed El-Hassan. "A Vision-Based System for the Inspection of Steel From Manufacturing." Automation in Construction 31 (2019): 104-116.

FUTURE WORK

- How can improved worker safety increase worker productivity? Research the correlation between these two.
- Pilot demonstration
- Work with factory designer for new modular layout for worker safety,⁹ i.e., easy access to PPE kiosks
- Work closely with OSHA so that they take notice of this safety niche
 - Audits or inspections by OSHA
- Develop new training models under OSHA, specific to modular factories
 - Provide video trainings
 - Require certification of factory safety

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